Innovative Approaches to Understanding Transportation/Societal Interactions

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16. Abstract

This report documents seven innovative approaches for analyzing relationships between transportation and spatial, social, and economic structures in the United States. The approaches were developed by six contractors as part of an UMTA/TSC research program. The report is divided into two volumes:

Volume 1 - Program Overview and Executive Summaries (88 pages) contains a description of the research program and executive summaries of the seven analytic approaches as documented in Study Design Reports prepared by the contractors.

Volume 2 - Study Design Reports (786 pages) contains the seven Study Design Reports which describe in detail the proposed analytic approaches.

The seven approaches and corresponding contractors are listed below:

Cambridge Systematics - Residential Housing and Location Model
DAA Enterprises - Systems Dynamics Model
Futures Group - Probabilistic Systems Dynamics Model
Interchange - Analysis of Demography, Housing and Transportation
Interchange - Micro-Economic Model
Research Triangle Institute - Comparative Analysis of Urban Spatial Structures
University of Illinois - Societal Linkages Model

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PREFACE

In 1979 the Transportation Systems Center (TSC), under sponsorship of the Urban Mass Transportation Administration (UMTA), began a program of research directed toward improving the understanding of the role of transportation in society, in particular with respect to patterns of travel, location and development. As a major element of the program, innovative approaches to defining, structuring or solving the problem were sought from the research community.

This report contains seven study design reports prepared by six research firms who were awarded contracts to produce detailed work plans for refining and demonstrating proposed innovative analytic approaches to understanding transportation/societal interactions. The research efforts described include development of: a residential housing and location model, a methodology for comparative analysis of urban spatial structures, two systems dynamics models, a micro-economic model, a societal linkages model and an analysis of demography, housing and transportation.

The report is divided into two volumes: Volume 1 contains the executive summaries of the study design reports, a description of the research program, and technical evaluations of the seven study designs by a TSC/UMTA review team; Volume 2 contains the study design reports.

This report was prepared by TSC's Urban and Regional Research Division under project funding from UMTA's Office of Planning Methods and Support. The work reported here was completed under the direction of Donald Ward of TSC. Project specification and overall program guidance were provided by Lee Jones of UMTA. Final preparation of this report was the responsibility of Michael Couture of TSC. The six contractors who prepared the study design reports and executive summaries contained herein were:

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University of Illinois at Chicago Circle
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Chicago, IL 60680

METRIC CONVERSION FACTORS

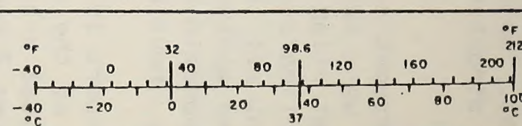
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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DTRS-57-80-C-00032

Innovative Approaches to Understanding Transportation/Societal Interactions

Study Design Report

Prepared for

U. S. Department of Transportation
Transportation Systems Center
Cambridge, Massachusetts

March 1980

Cambridge Systematics, Inc.

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* Section not included

1. INTRODUCTION

1.1 Overview

This report presents an approach for the study of long-run interactions between transportation and housing type/residential location choice in urban areas. The strategy suggested is intended to address the possibility that significant changes in factors such as technology, fuel supply and demographics may dramatically alter the context in which future transportation and housing choice decisions are made. The approach is based on a general conceptual framework encompassing all urban spatial phenomena, with a focus for immediate study on the area of residential location and housing. The area of housing and location of residences was chosen because of its critical role for policy analysis and its potential for the development of a long-run model whose temporal validity can then be tested. This immediate focus on residential demand is motivated by the crucial importance of understanding the household decision process as a determinant of long-run changes in urban density patterns.

The general conceptual framework is characterized by a disaggregate or micro-behavioral perspective. All spatial decisions are viewed as made by different actors in a dynamic response to a range of attributes; some of these attributes may be wholly exogenous, and others may be the result of choices of other actors. For example, each household is a

distinct actor and makes choices regarding its location and residence. These decisions are influenced by both the decisions of other households (which determine attributes such as neighborhood composition) and decisions of other types of actors such as landlords, retail firms or manufacturers. The framework is also explicitly dynamic in that choices are made over time and can depend on the complete history of prior choices as well as expectations of future ones.

The study approach is structured in two stages. The first stage entails the generation of a set of scenarios representing possible alternative conditions of factors that can have a major impact on key policy issues. This is intended to account for the potentially significant changes in socioeconomic characteristics of the population, resource costs and needs which could occur in a time horizon of 30 years. Alternative scenarios are specifically formulated to address a range of possible changes which may have significant impact on spatial location patterns and hence urban transportation demand.

In the second stage of the analysis, a set of more formal, econometric models are developed to predict dynamic changes in residential location and housing choice, based on the underlying exogenous conditions defined in each scenario. Changes in demographic characteristics of the population and the dynamics of household location changes are modelled in an explicitly dynamic framework, as forecasts for each time period are conditional on prior characteristics and choices. Forecasting to the aggregate level is performed by the "sample enumeration" procedure (Kopppelman, 1976; Lerman, 1978), a form of Monte

Carlo simulation. This approach, by utilizing micro-level data and forecasts, permits the use of models at the individual level without the need for assumptions regarding the homogeneity of particular subpopulations or the functional form of the distribution of population attributes.

1.2 Research Needs

There is a broad literature of previous studies of urban spatial location patterns performed by geographers, planners and economists. Nevertheless, these studies have primarily focused on static conditions and small period changes. There clearly remains a need for further approaches to the problem of long-range change. One crucial set of questions pertain to the relative roles of demographic shifts and social aspects of neighborhood change on spatial location behavior and hence transportation behavior. Another set of issues concern the long-run impacts of energy availability, factor costs and technological change for the locational distribution of residences and employment. For example, the current concern for future energy availabilty raises serious questions regarding spatial structure in the U.S.: Can the relatively low density, auto-oriented urban form we currently have be sustained? Will more dense patterns (as in Europe) result from higher energy prices, or will more focused policies be required? How long will it take to achieve major changes in spatial structure, and will the transitions that might occur produce serious public policy problems? What is the potential role for transportation as a policy instrument to encourage various spatial structures?

A TSC study (Ward, et al.) in 1977 noted that "the long term effects of transportation technology on patterns of residential and business development change, and on the resulting level and quality of interaction and communication have rarely been considered." The situation has not changed significantly since that time. There has been a growing recognition of the importance of transportation tradeoffs by consumers. In general terms, consumers make personal choices regarding residential density and location based on a series of housing, neighborhood, job and transportation tradeoffs. It is clear that transportation is only one element of what has been termed the "total activity system" in which each household is involved. Yet, the actual importance of transportation accessibility as a determinant of residential location and housing choice is still not well understood.

1.3 Motivation: Tradeoffs Between Transportation and Other Factors in Residential Location Choices

Urban areas in the United States in the past 30 years have experienced an increasing move of their population away from central city areas to low density suburban areas. For example, in 1948, in a sample of 40 large US metropolitan areas, 36 percent of the total population resided in suburban areas; by 1963, this figure was over 54 percent (Kain, 1967).[1] This relatively rapid population dispersal has resulted in a fiscal and economic decline of many central cities, while in many cases costs of providing public services in outlying areas have

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[1]As of 1970, the proportion residing in suburban areas had increased to 57 percent.

increased. The additional operating expenses borne by local governments because of dispersed, large-lot, single-family home development rather than clustered townhouse development has been estimated to be as high as 100 percent for street costs, 42 percent for utilities, and 18 percent for school costs (Real Estate Research Corporation, 1974). Low density residential developments also have had the effects of increasing trip lengths (Balkus, 1967; Rice, 1978; Pushkarev and Zupan, 1977), with resulting increases in energy consumption and air pollution. Finally, as both workplaces and residences have become more dispersed, the provision of cost-effective public transit has become increasingly difficult.

Improvements in the relative accessibility of central city areas (via enhanced transit and restricted highway systems) have often been viewed as potential means of encouraging greater downtown activity. Indeed, one of the missions of UMTA has been stated as "to encourage efficient land-use patterns and restore central cities" (Orski, 1977).

Other federal and local efforts have either explicitly or implicitly focused on improving the attractiveness of central cities in other ways. For example, housing subsidies, improved law enforcement, federal grants allowing reduced property taxes and aid to urban school systems all have the potential for decreasing net migration out of large central cities. For policy- and decision-makers, the crucial questions in choosing an allocation of resources among these various options has to do with their relative efficacy in achieving desired goals. To the extent which one of those goals is reducing suburbanization, policy- and decision-makers must be given insights into how much each of these options can influence urban location decisions.

Unfortunately, the underlying process by which firms and households reach decisions to relocate and move to suburban sites is not particularly well understood. It is evident that the decisions of firms and households interact, typically in a mutually reinforcing fashion. For this reason, it becomes important for long-run policy analysis to understand the relative effects of various policy options on the urban location process.

The importance of focusing on consumer housing and location preferences (demand) as a factor in urban development patterns is underscored by the high rate of residential mobility in the United States. Approximately 42 percent of the nation's population changes its place of residence every five years (US Census, 1975). Nearly half (45 percent) of these moves are within the same metropolitan area. Thus, at least in terms of consumer demand, there is a strong potential for significantly long-term shifts in housing patterns between suburban and central city areas, and perhaps equal potential for slowing or even reversing current trends.

1.4 Organization of the Report

The study approach presented in this report is based on the premise that major aspects of transportation-land use interactions have been missed by previous urban land use models. Chapter 2 presents a critical review of theoretical and applied models of urban location patterns, with specific attention to their limited sensitivity to both long-run dynamic changes and the role of non-transportation factors. Studies of

residential mobility and location behavior are also briefly examined in order to better identify the major issues and problems for long-range urban spatial modelling.

Chapters 3, 4, and 5 develop the general framework for a micro-level analysis of long-run transportation-societal interactions. The theoretical framework in Chapter 3 begins with an approach for organizing the interrelationships of actors and actions affecting urban spatial development patterns. Practical considerations for defining geographic scale, temporal stability, and aggregate forecasting procedures are discussed. A theoretical approach for modelling household location decisions and long-run changes in urban residential location patterns is then presented.

Chapter 4 presents a classification of major components for the development of future scenarios. The construction of scenarios is a major focus of the study approach, and is designed to represent exogenous changes in economic and lifestyle patterns that may (in the long run) influence spatial location and travel characteristics. Chapter 5 then presents the procedures for making aggregate impact forecasts on the basis of the micro-level models and scenarios.

The end product of the Study Design effort is an outline of the proposed analysis, which is presented in Chapter 6. This consists of structural equations, a review of potential data sources and descriptions of specific scenario packages to be tested. The possible applications and benefits from the study approach are then summarized.

2. LITERATURE REVIEW

Theories of land use and urban spatial structure have always given transportation accessibility a significant role in determining the location patterns of various activities. There has been much attention in both the disciplines of urban economics and geography given to theories of the spatial allocation of activities. In addition, various large-scale land use simulation models have been developed in the last twenty years for application in the metropolitan transportation planning process. As discussed below, there have already been quite a few published reviews of both the theoretical models of urban land use and the large-scale forecasting models. A repetition of such reviews for this report would serve little purpose. Rather, this chapter presents a critical review of the current state of theoretical and applied urban spatial models. Attention is focused on limitations of the current approaches for application to long-range forecasting and the identification of transportation-societal tradeoffs. In this way, we may identify the major needs for improved model frameworks.

2.1 Theoretical Economic Models

Early efforts at explaining the specialization in use of agricultural land (e.g., Von Thunen, 1842) and models of central place formation (e.g., Losch, 1954; Christaller, 1966) relied almost exclusively on transportation costs to account for particular spatial patterns of economic activity.

Formal economic "bid-rent" models (Alonso, 1964; Mills, 1972; Muth, 1969) were a natural extension of these theories to explain urban structure. The bid-rent models assumed that the residential location choices of individuals are determined by a tradeoff between the increasing costs of commuting to work and the decreasing unit prices of housing and land associated with living further out from the central place of employment. Households (and similarly, firms) thus compete for location and area in order to maximize their benefits, subject to a budget constraint and a resulting market rent gradient.

Given an assumption that the hypothetic city is monocentric and circular on a geographically featureless plain, the bid-rent theory determined residential density patterns as a function of distance from the city center. The bid-rent model was important in that it represented a formalization of the interdependence between transportation and urban spatial development.

The theoretical bid-rent models have had some limited application (Mayo, 1973; Wheaton, 1974). Extreme simplifying assumptions greatly limit their applicability for policy analysis. Andersson (1976) summarized the limiting assumptions of these models, which include:

1. All employment is located in the city center, which is surrounded by the residences.

2. Only housing and commmuting costs are considered, ignoring the role of non-work accessibilty and many other locational amenities.

3. The city "owns" all the residences, as there is no differentiation of the economic aspects of renting versus owning.

4. No differences exist in tastes (preferences) between households, other than income and budget constraints.

5. The tastes of households are neutral between living in highrise buildings or single family houses, as only total living space is important.

6. All differences in comfort between the modes are reflected in differences in the value of time.

In particular, it is important to note that the omission of many aspects of location beyond commuting transportation costs has contributed to potentially exaggerated conclusions about the magnitude of transportation effects on location decisions.

There have been some attempts to broaden the urban economic theory to overcome some of the above limitations (Wheaton, 1974). Bid-rent theory can be adapted to multi-centric cities, although it is still not applicable for situations with highly dispersed employment patterns. Models of "hedonic price indices" attempt to estimate monetary values for various housing and neighborhood attributes (Ridker and Henning, 1967; Kain and Quigley, 1976; Merrill, 1977). These hedonic price models, in common with bid-rent theory, assume that observed prices reflect a static equilibrium of utility preferences. Thus, the long-run dynamics of the urban development process and the possibility of short-run disequilibria are not addressed. Of course, it should be recognized that the urban economic theories of bid-rents were never intended to be comprehensive; rather, they were formulated to explain only limited aspects of the extremely complex process through which spatial structure is determined. In order to achieve analytically tractable results, much of the richness of urban structure must of necessity be abstracted.

2.2 Aggregate Zonal Models

Since the mid-1960's, there has been a continuing evolution of comprehensive urban land use models designed to forecast the spatial distribution of urban activities. Designed as an input into the metropolitan transportation planning process, these models forecast the distribution of population and employment activities among zones in a metropolitan area. The models include: EMPIRIC, PLUM, TOMM, USM, ALD, DRAM, LUPD, LAPD, USM, LUAM and others. Most are derivatives of a few basic approaches, most notably the Lowry (1964) model. There have been numerous reviews of these models in the published literature, so a further broad review would contribute little new. (For detailed discussions of the different urban land use/transportation models, refer to: Lowry (1968); Brown et al.(1972); Chan (1973); Putman (1975); Gomez-Ibanez (1975); and Moore et al. (1975).)

More recent attempts to integrate spatial allocation models and transportation models (ITLUP and TRANSLOC/TRAMM) are describid in Putman (1976) and Lundquist (1978). (Another urban simulation model, the NBER model, is discussed separately because of its more micro-level orientation.)

The comprehensive land use or urban development models are typified by the use of zonally aggregated population and employment data, and empirical estimation of variable relationships and zonal attraction functions based on observed correlations. This aggregate approach has been the subject of criticism from several directions. Lee (1973) criticized the large scale models of the time for their high level of

spatial and demographic aggregation, their enormous data needs, and their basis in mechanical approaches and correlations rather than causal relationships. Putman (1975) characterized such models as "macro-descriptive," and criticized the aggregate model approach along with the gravity model of zonal trip distribution, arguing that it "seems to describe a variety of social phenomena without a genuine correspondence between its formulation and the observed behavior of individuals."

Most of the aggregate spatial interaction models are based on the assignment of zonal attraction factors, determined by some variation of the "gravity model" framework. The gravity model was originally derived empirically, but is also derivable from entropy maximization theory (Wilson, 1976) and from utility maximization (Beckman and Golob, 1972). Regardless of its theoretical justification, the applications of zonal gravity models have still been subject to the criticism that they describe observed behavior with limited justification in individual human behavior.

The large-scale land use models, like the economic bid-rent theories, have also been subject to the criticism that they ignore many non-transportation effects on location patterns and the dynamic nature of urban development. Gomez-Ibanez (1975) identified the limitations of many comprehensive land use models. These include:

- o By focusing on the commute trip, they ignore accessibility for other trip purposes that may also be important for location behavior.

- o They ignore many non-transportation variables such as zoning, racial discrimination and public services.

- o As static equilibrium models, they incorporate no dynamic adjustment. They ignore the constraints of current buildings and neighborhood infrastructure already in place.

The importance of dynamic adjustment in urban development cannot be ignored for long-range analysis. Cheslow and Olsson (1975) point out that the static equilibrium models, by ignoring the constraints on development from already existing buildings and infrastructure, have the tendency to overestimate the influence of transportation on future land development patterns. In developing the NBER Urban Simulation Model, Kain, Ginn, et al. (1973) explicitly recognized that an equilibrium of supply and demand for housing and land is never reached at any single point in time. This is primarily because the physical durability of buildings and infrastructure, together with high costs for demolition or renovation, can frequently lead to the continued existence of facilties beyond their lifetime of efficient economic usefulness. The need for development of models incorporating dynamic disequilibrium was a dominant issue at a 1977 conference (Hensher and Stopher, 1977).

2.3 Importance of Micro-Level Interactions

There is a growing recognition that a comprehensive understanding of transportation/land use relationships requires a theory of the decison processes of individual households and firms. Britton Harris et al., as far back as 1968, argued that the direction for improving the accuracy of urban models lies with "micro-level" studies of the behavior of decision-making units, rather than with more zonal data collection. At the heart of the issue is the need to incorporate socioeconomic effects on long-run residential location patterns. In the long term, changing

lifestyle trends, family structure, household size, labor force participation rates and income-related recreation trends can have major implications for the residential location bahavior of individuals. The macro models operate on a level too aggregate to be sensitive to the great range of household characteristics and their lifestyle implications. (The Urban Dynamics approach to modelling, e.g., Forrester (1969), shares this aggregate level insensitivity to variations in socioeconomic characteristics.)

Among the large-scale urban simulation models, the NBER model is unique in that it operates with micro-level (individual household) data. The initial version is documented in Ingram et al. (1971 and 1972), although the model has since undergone significant evolution (Kain, Apgar and Ginn, 1976). The micro-level forecasting technique developed for the revised version of this model is discussed in Chapter 5. It is nevertheless notable that the NBER model shares with other large-scale models the problems of complexity--large computer time and data storage demands, and compromises in the complex submodel relationships.

2.4 Small-Scale Analyses of Transportation Tradeoffs

Besides transportation accessibility, there is a variety of other residential location attributes that may affect the housing and location choices of households. These may include the age, income, and racial composition of neighborhoods, residential density, and the size, quality, condition and price of the housing stock. In addition, the level of public services such as schools, police, fire, and recreational services are determined at least in part through local property taxes, and thus vary widely between communities.

There has been significant research by geographers, sociologists and economists examining the relative importance of neighborhood, housing and acessibility attributes in determining the mobility and location behavior of households (e.g., Butler, et al., 1969; Moore, 1972; Speere, et al., 1974; Barret, 1974; Quigley and Weinberg, 1976). In general, it is concluded that housing attributes, neighborhood amenities and social ties to neighborhoods are more frequent determinants of residential mobility behavior than transportation accessibility concerns.

Many of the residential and employment mobility analyses have examined the phenomena that many individuals fail to change homes or jobs in the face of superior alternatives elsewhere. It has been noted that both intra-metropolitan moving and regional migration behavior are subject to the property that the longer an individual remains in place, the less likely that individual is to move from there. This "cumulative inertia" property of locational change behavior has been the motivation for the use of models which incorporate duration of stay at a place as a determinant of the probability of relocating. Morrison (1971) confirms this hypothesis in the US by demonstrating that a disproportionate share of migration is done by a small portion of the population who are relatively "footloose." Ginsberg (1971, 1972a, 1972b) has further developed this concept to motivate the use of non-Markovian models (i.e., state transition models in which the probability of a transition in some interval of time is not independnet of the time since the last transition).

Mueller (1978) has developed a disaggregate model of migration which at the theoretical level distinguishes among three different causes of "cumulative inertia". The first is job tenure, i.e., the length of time an individual is in a job. As workers gain seniority at a job, they are in essence accumulating an asset (job security and wage increases resulting from seniority) which is not fully transferrable. The second type of tenure is industrial tenure, i.e., the length of time an individual is in a given industry. Basically, the longer a person works in an industry, the more specialized skills he or she obtains in a specific industry, thereby reducing the job possibilities with comparable compensation elsewhere. The third type of tenure is locational tenure. This reflects the costs (both economic and noneconomic) associated with leaving a residence. All three forms of tenure act to discourage residential or employment mobility.

The limited importance of transportation characteristics as determinants of residential location is underscored by a number of recent rail transit impact analyses. Studies of the new BART rail system in San Francisco have found its impact on residential location patterns in the area to be smaller than expected, indicating that the role of transportation in determining location choices was overestimated (Metropolitan Transportation Commission, 1977). Much similar evidence compiled for a range of transit systems by Knight and Trygg (1977) substantiate this result. In addition, empirical studies by Boyce et al. (1972), Dornbusch et al. (1976), and Lerman et al. (1978) have explored the impact of rail transit systems on real estate prices in Philadelphia, San Francisco, and

Washington respectively. These studies are typically multivariate regression analyses which attempt to infer the relative contribution of various determinants of property values. Generally, as a group they have concluded that transportation has a small but statistically significant impact on the prices paid for residential real estate.

2.5 Disaggregate Models

Another group of recent empirical studies by Mayo (1973), Friedman (1975), Lerman (1975), Pollakowski (1975) and Weisbrod (1978) have examined the impact of socioeconomic factors and the level of public services on the actual location decisions (as opposed to prices paid) of households. All are based on utility maximization theory and, except for Mayo, are based on discrete choice logit analysis. As a group, these studies provide evidence for several conclusions:

1. The effect of transportation access on location choice decisions is overshadowed by household income and size considerations. In particular, it is clear that housing costs are a very important aspect of residential location decisions. A small change in housing costs can have an effect on residential location decisions equivalent to the effect of a larger proportional change in travel time. Since many US cities are experiencing rapid increases in real housing prices, it is important to recognize the potential impact of shifting price patterns. Depending on how they are structured, rent control, rent subsidies, tax advantages, mortgage ceilings and other price-related policies can potentially offset or enhance the impacts of transportation investments.

2. The level of community expenditures on police, fire, education and recreation services are less important factors in location choice for most households than is transportation accessibility to work. On the other hand, efforts to reduce crime rates (and possibly other aspects of the living environment) may contribute to increasing the attractiveness of some locations as much as proportional improvements in transit travel time.

3. Factors beyond the scope of public policy, such as the desire for single-family detached homes among families with children, affect residential locations more than other factors related to public expenditures. Thus, there may be large changes in residential preferences which are for the most part only marginally influenced by available policies.

The theoretical framework for disaggregate choice models is outlined in Chapter 3.

The above-referenced residential location models have the advantages that they are based on the behavior of individuals and are sensitive to both socioeconomic variation among households and incorporate a wide variety of non-transportation attributes of locations. They nevertheless still have a drawback in that they assume current housing location and travel patterns to represent a static equilibrium condition. The only exception is the model developed in Weisbrod (1978), which is an extension of the framework in Lerman (1975) to a dynamic-recursive approach. The framework is dynamic in that only marginal change in location and housing choice patterns is estimated, based on separate models for: (1) residential mobility, (2) the location and housing choices of movers, and (3) short-run travel choices. It is recursive in that moving decisions depend in part on the estimated utility of current and alternative residential locations, and location and auto ownership decisions depend in part on estimates of the travel accessibility for each mode choice.

The approach of modelling location choice only for movers in a given period is based on the belief that only recent movers may be in some form of equilibrium with respect to their tradeoffs of various housing and neighborhood attributes of their residences. It is misleading to analyze the tradeoffs for households who have not moved in recent years, since job location, household size, household income, and neighborhood characteristics in the intervening years may have changed from the time the original tradeoff decision was made. Households' adjustments to these changes are not instantaneous because of the high transaction costs associated with moving. This is particularly the case for owner-occupiers and elderly households, for whom the physical and psychological burden of moving may be significant.

2.6 Problems for Long-Range Urban Spatial Modelling

The theoretical models and their applied forms discussed above have all involved extensive simplifying assumptions which have limited their application for some policy problems of relevance. There are a number of good reasons why no single comprehensive theory of the interaction between transportation and spatial structure has emerged. Perhaps the most significant of these is that the actual process is extraordinarily complex. Some of this complexity arises from the following considerations:

- dynamic effects--Most spatial phenomena of interest result from the actions of numerous decisions made over relatively long time periods. In most of this situations, previous decisions play an important role in determining current choices, and the dynamics of change over time are significant.

- o <u>high transactions costs</u>--Many spatial choices involve the construction of relatively immobile capital; this immobility implies very high transaction costs for certain types of spatial decisions, and discourages relocation even when such changes may be desirable.

- o <u>role of uncertainty</u>--Because many special choices have high transaction costs, they are often based (at least in part) on a set of assumptions about future conditions. For example, households choosing a residence (particularly those seeking owner-occupied dwellings) must be concerned not only with the current quality of potential neighborhoods but also with future changes in the quality of those neighborhoods. These factors are highly uncertain and may encourage either overly conservative decisions or speculation by brokers and developers.

- o <u>role of non-transportation factors</u>--Transportation is only one of many factors which influence spatial structure, and in many cases may not be the dominant determinant of spatial patterns. Great care must be exercised to avoid attributing the effects of these other factors (e.g., schools, taxes, land prices) to transportation.

- o <u>multiplicity of actors</u>--There are an enormous number of individual actors, each of whom makes spatial choices. These include individuals choosing workplaces, households choosing residences, firms choosing plant sites, government agencies selecting service delivery sites, local governments setting taxes and developers locating infrastructure.

- o <u>interdependent decision processes</u>--Each individual's decisions about where to locate may depend on the choices of others. For example, neighborhood quality is in part determined by who else lives there. Thus, each actor's decisions may not be made independently of the choices of others.

2.7 Integrating Urban Spatial Models with Regional Economic Models

While we are focusing attention on theories and models of intra-metropolitan spatial location patterns, it must be recognized that cities are not closed systems. Capital investment and employment opportunities all change over time, and are subject to migration between

cities and between regions. The spatial development of urban areas is sensitive to the growth and decline of the local economy and population base.

Inter-regional income and commodity flows have been the subject of a broad set of models, mostly variations on the well-advanced technique of input-output modelling. These models include:

- o Harris-Hopkins (1972) Multi-Regional, Multi-Industry Forecasting Model
- o Leontief-Strout (1963) Multi-Regional Input-Output Model
- o Freidlander et al. (1977) Model of Freight Rates, Commodity Flows and Regional Income
- o Polenske (1970) Multi-Regional Input-Output Model
- o Harvard-Brookings Macro-Economic Transport Model (Roberts and Kresge, 1971)
- o Stein and Mosback (1971) Multi-Regional Input-Output Model

The above models represent inter-regional flows of products and purchases stratified by economic industry (sector). They are applicable for modelling the regional impacts of various government policies, and are sensitive to transportation costs. More specifically, sources of supply for various products are determined by product costs in different regions and by costs of transportation between regions. Knowledge of each region's demand for each commodity and of its sources of supply generates a matrix of interregional commodity flows, which can be used to determine the production of every commodity that must take place in each region. Production levels then determine employment, wage levels, and per-capita income.

A notable attempt to link an urban spatial allocation model with a model of regional economic change is the framework developed by Engle and Rothenberg at MIT (Engle et al., 1972). The Engle-Rothenberg Econometric Simulation Model involves three submodels:

1. A static macro-economic submodel of industrial output, employment and income for an SMSA

2. A dynamic model of long-term growth or decline in metropolitan population and capital investment by industry.

3. A spatial allocation model to predict the location patterns of residences and businesses on the basis of supply and demand equilibrium

While the spatial allocation model is an equilibrium approach, it is linked to the dynamic model of metropolitan economy (models 1 and 2, above). Locational demand is determined in part by the level of population and industrial output in the metropolitan area, together with the distribution of income and prices, all of which are output from the metropolitan economy models. Similarly, supply changes from new construction and building conversions are estimated on the basis of the stock of land and structures previously available, together with measures of construction costs and costs of capital determined from the metropolitan economy models.

The Engle-Rothenberg model framework is complex and was never fully implemented. (The residential location component is reported in Bradbury, 1974.) Nevertheless, this modular approach suggests the possibility of linking separately-developed urban land use modes and regional location models. In this way, the full range of transportation, economical land-use interactions may eventually be analyzed in a framework linking the national, regional and intra-urban levels.

3. CONCEPTUAL FRAMEWORK: THEORETICAL MODEL

3.1 Focusing the Problem for Analysis

This chapter is organized around a progression of three discussions: (1) a general framework for defining and classifying transportation/societal interactions, (2) a series of guidelines for narrowing the immediate analysis to the area of urban spatial analysis, and (3) a theory of micro-level behavior of dynamic change in the spatial location and related transportation demand decisions of households.

The first discussion outlines the general framework for structuring the analyses of spatial form. No attempt is made to present a comprehensive theory explaining all spatial phenomena of potential interest. Rather, the general framework is designed to define a perspective for organizing subsequent analyses, by defining the relevant boundaries for spatial analysis and identifying the major decisions and decision-makers that can influence relevant spatial phenomena.

On the basis of the general framework, the immediate study is narrowed to focus on the issue of metropolitan spatial form and the relevant role played by urban transportation in that context. Guidelines for defining this issue are developed on the basis of major policy issues affecting long-term change. Following a narrower definition of the issues for immediate analysis, a specific theory of the micro-level decision-making process is developed for the long-term dynamic modelling of residential location, employment location, auto ownership and travel demand patterns.

3.2 General Framework[1]

A. Systems Classification

Transportation interactions with society and the quality of life occur through several mechanisms on several levels. The system mechanisms are:

- o economic systems--the growth and decline of industries and firms; the flow of capital investment between firms, industries and geographic locations; changes in employment opportunities among industries and locations; distribution of income.
- o demographic systems--family structure; population migration and housing location patterns; labor force participation rates.
- o social systems--neighborhood quality; social/ethnic ties; use of social and recreational amenities.
- o physical systems--spatial land use distribution of firms and population residences; changes in building and urban infrastructure; environmental quality.

Growth and change in each of the above systems occurs in the dimensions of spatial location distribution and economic activity sector distribution. Both classes of changes involve decisions by individuals and firms within the constraints of various input supplies and regulations, and are manifest on at least two distinct spatial scales:

- o metropolitan regional growth and inter-regional distribution
- o intra-urban distribution.

Different systems operate on distinct geographic levels. The growth and distribution of many sectors of the economy occur on the inter-regional level. Relative differences in the cost of services, raw

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[1]Some portions of this general framework were originally developed in Transportation Impact Evaluation System, Cambridge Systematics, Inc., 1979.

materials and other production inputs are responsible for inter-regional shifts in commercial investments and labor demand. Freight transportation requirements and the migration of population are both affected by changing economic growth patterns among regions. On a different level, the spatial locations of housing and other land uses occur in the form of intra-metropolitan spatial development, with competition among neighborhoods and local community jurisdictions.

B. Micro-level Orientation

The organizing principle upon which the framework is based is the individual decision-maker as the ultimate source of all spatial activity phenomena. Thus, the perspective embodied in the framwork is a disaggregate approach, in which the individual decision-maker (person, household, firm or other agency) constitutes the basic unit of analysis. Although the micro-level perspective proposed is consistent with much of existing theory in such fields as microeconomics, social science, and travel demand modelling, this approach has not been directly operationalized to date in most applied empirical studies of spatial form.

Individuals, firms and government agencies all interact to make a great number of decisions concerning the level of various activities and spatial location patterns. There is no clear mapping between the different types of individual decision-makers and the types of decisions made. For this reason, a micro-level analysis should highlight the functional decisions of interest rather than just a classification of the types of individuals and organizations making them. Five functional categories for classifying decision-makers are suggested:

- o individuals and households
- o producers
- o regulators
- o suppliers of infrastructure
- o service operators and transaction agents

It is recognized that an individual decision-maker may at various times operate within multiple functional categories.

Table 1 summarizes the relevant choices and constraints attributable to each functional category of decision-makers. Obviously, these individuals and organizations make a vast multitude of decisions on a wide variety of topics, of varying degrees of relevance for the analysis of long-term shifts and interactions with transportation. The list of decisions presented here is limited to a manageable subset considered most relevant for the long-term study of economic activity and spatial location. A simplified representation of the interrelationships between decision-makers and their effects on urban spatial structure is shown in Figure 1.

It should be stressed that the adoption of a micro-level behavior perspective does not in itself require the application of modelling techniques using disaggregate data. Models operating on aggregate level data may be viewed as representing the sum of individual decisions. Many regional economic issues and some spatial problems might be analyzed effectively with aggregate level data. The particular value of using individuals as a starting point for a conceptual framework is that it forces an explicit consideration of the implications of data aggregation.

TABLE 1

Actors and Relevant Choices

Functional Category	Choices and Constraints
individuals and households	labor force participation workplace location residential mobility residential location housing auto ownership mode to work
producers	entry or exit location structure type size of structure employment points of purchase modes/shipment sizes for purchase and sale
regulators	feasibility constraints (zoning) linkage constraints (entry requirements, parking provision requirments, environmental constraints) operation constraints (price regulation, entry regulation, comon carrier requirements, anti-trust laws safety requirements) fiscal (taxes and subsidies)
suppliers of infrastructure	location type of facility pricing scale of facility
service operators and transaction agents	prices service levels fleet decisions capital availability (credit)

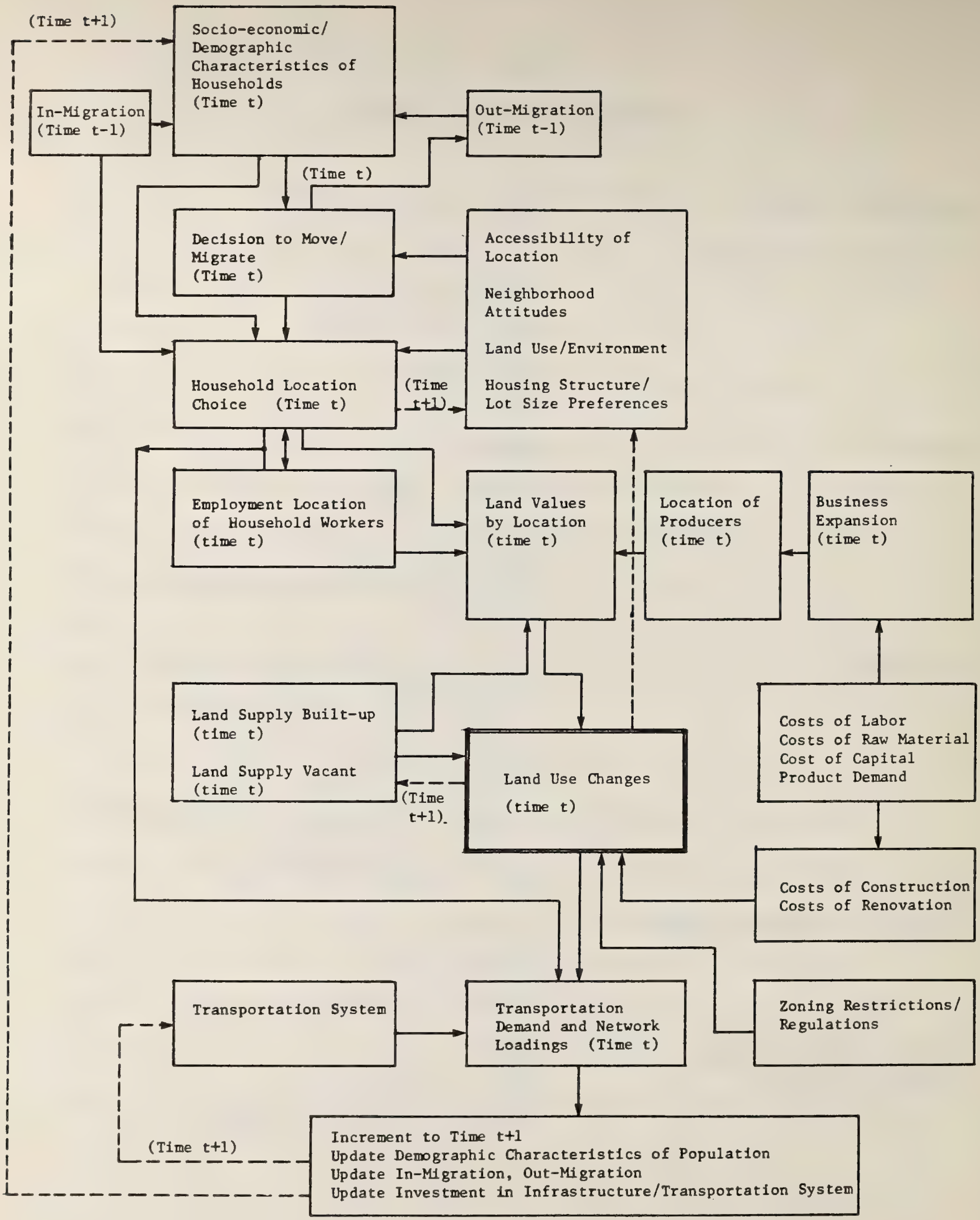

FIGURE 1

Model Framework for Land Use/Transportation Change

C. Explanatory Factors

Consistent wth a behavioral framework, the above-referenced decisions of each individual or firm are assumed to depend on changes in conditions that are exogenous to that actor. These may be classified into three basic types of variables:

1. factors exogenous to the entire framework,
2. factors exogenous to the individual decision-maker but endogenous to other actors in the framework,
3. factors resulting from the interaction of different types of actors.

Factors that are exogenous to the general framework include physical attributes of the geography, technology, climate, national demographic trends and federal government policy. The second category includes the behavior of other firms and persons, including location, land use demand, travel characteristics, income and economic competition. It is important to note that individual decision-makers may regard specific conditions as exogenous, which are in fact subject to the influence of an aggregation of similar actors. For example, a large developer's pricing decisions for new houses may be viewed by any one household as exogenous, and the household is strictly a "price-taker". However, the aggregate behavior of all households can influence new house prices in the sense that developers realize that increasing their prices will result in reduced aggregate demand for new houses.

The third category includes prices for various goods, new building construction and land development. On an individual level, most of the actors are "price takers" rather than "price makers"; the prices at which they can sell their goods is largely determined by the prevailing

market. Only regulators, operators and transaction agents can play a role in price setting. Subsequent sections address the topic of equilibration in a long-term dynamic model framework.

D. Dynamic Change

Having specified the decisions of interest for each category of decision-maker and the role of exogenous variables, the next step in the conceptual development of a framework for spatial analysis is to specify a process linking the two. A key feature of the framework is a dynamic structure for this process, in which choices are represented as changes from an existing state which are caused by exogenous events and decisions, including all previous choices and expectations regarding the future. In this way, all long-run forecasting is based on a process of incremental changes over a number of limited length periods. The approach of "static equilibrium" is explicitly rejected in favor of a "marginal adjustment" model framework.

It is recognized that even within horizons of 30 years, it is not realistic to reallocate the spatial distribution of all urban activities, nor is it realistic to reallocate the distribution of labor and facilities among economic sectors. Given the durable nature of in-place building structures and infrastructure services, changes in urban spatial development and economic development will tend to occur in the form of increments from the current characteristics. Costs of new construction, structure conversion and investment capital all act as barriers to major reallocations of activities within cities and within industries. In the case of urban spatial development, future land use patterns are viewed in terms of a staged decision process:

1. Given: Previous period land use patterns

2. Decision of a current household or firm to relocate

3. Location choice, given decision to relocate (or formation of a new household or firm)

In the context of utility theory, it is explicitly recognized that the locations of many households and firms do not represent a static equilibrium. The probability of a current household or firm relocating in a future period depends on whether the expected advantages of possible alternative locations outweigh the full costs associated with relocation,[1] e.g.:

$$\text{Prob (move)} = a(U_A - U_C) - b(M)$$

where:

U_A = expected value (utility) of possible alternative locations

U_C = estimated value (utility) of current location with possibility of renovation/conversion

M = estimated costs of moving

a, b = coefficients

Only the locational choices of movers is viewed as representing a short-term equilibrium, and even that occurs within the constraints of building supply, land use availability, construction costs and other socioeconomic neighborhood factors. Many of these constraining factors are explicitly recognized as the product of current and previous decisions made by other households and firms. Given the dynamic

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[1]The importance of barriers to residential mobility is discussed in Weisbrod and Vidal (1978). More generally, the separation of the decision to move from the residential location decision is supported by Rossi (1955), Pickvance (1974) and Moore (1972).

structure of the framework, there is no long-term equilibration of supply and demand. Only the short-term adjustments of prices represent the movement of market forces at each point in time toward an ever-changing short-term equilibrium.

3.3 Practical Considerations for Urban Spatial Modelling

The general framework identifies the underlying theory and the relevant actors and issues for a broad analyses of transportation-societal interactions. The next step in the development of a study design is to further develop the theoretical framework for a more focused aspect of long-run transportation impacts. This strategy is motivated primarily by practical considerations; it is clear that a comprehensive analysis of transportation impacts on all aspects of society is not realistically possible nor is this type of goal even within the scope of current funding levels.

The remainder of this section discusses various practical issues and concerns for focusing the study of urban spatial location.

A. Geographic Detail for Studying Spatial Patterns

Virtually all spatial analyses require some description of the location of activities. These locations can be treated as points in some coordinate system; however, as a practical matter, it is usually more useful to partition the area under study into geographical units. Such units may be traffic analysis zones or census tracts, or they may be cities, counties, states, or regions. Such geographic subdivisions are frequently incongruent in the sense that relating models from one geographic system to another may be difficult.

Spatial analyses are necessarily conducted over a broad range of geographical scales. These include micro-level studies of local neighborhood change, metropolitan level studies, and regional studies, as well as studies at a national or international scale. The data and analysis needs at these different scales obviously differ in significant ways. These scales are often <u>not</u> arbitrary. Phenomena such as neighborhood change, intercity population shifts and regional commodity flows take place on specific geographic levels. A model of location behavior must thus be sensitive to changes occurring on these specific geographic levels, although it can still be useful to aggregate forecasts for a larger geographic area or to infer forecasts for a finer geographic breakdown.

A persistent criticism of most Systems Dynamics applications to urban analysis has concerned the highly aggregated spatial level at which they typically have operated. The traditional focus of urban dynamics on community employment and population change has been applied to forecast stages of growth and decline of urban areas. This approach is not sensitive to change in life style activity patterns or resulting policy implications for trip generation and distribution characteristics of urban travel. It is for these reasons that the current study approach should be organized on the level of small-area analysis districts.

B. Temporal Stability

An appropriate dynamic model should be sensitive not only to change in spatial states over time, but also to temporal changes in behavioral relationships. Such a model representation is a recognition that forces

that have changed spatial patterns in the past may not necessarily continue to do so in the future. For example, the relationship between residential location decisions and transportation mode decisions is a classic example of temporal change in relationships. Historical studies indicate that the importance of transportation considerations as a determinant of location choice for household residence (and firm location, for certain industries) has declined over time. This change is attributable to rising incomes, new technology for production inputs and life style changes that have allowed the substitution of other activites for some travel previously necessary. This example underscores the importance of explicitly controlling for exogenous economic, technological and demographic shifts in any analysis of long-term transportation interactions with spatial form. It also suggests the importance of validation for temporal transferability; a useful long-term model for policy analysis should be calibrated on real data for at least one location and then tested and corrected on the basis of similar data for a different point in time.

C. Linkage Between Macro-Modelling and Micro-Level Models[1]

Before discussing the practical problems associated with the macro-level, or aggregate, modelling approach, it is useful to first formalize the structure. In particular, many macro models for spatial location change are implicitly "transition matrices," which involve

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[1]Portions of this section were developed in a paper by Lerman and Weisbrod (1979) for the Netherlands Ministry of Transport.

forecasting changes in spatial location patterns in terms of zonal cell probabilities for classes of households or businesses. This concept is theoretically similar to a rather large body of research which attempts to describe moving and location behavior as a Markov process. In this way, probabilities of employment and population locational changes can be estimated by counting the number of moves between all workplace/residence zone combinations.

The two general modelling approaches termed "macro" and "micro" level should not be viewed as logically distinct. While these two approaches are as a practical matter very different, they both can be derived from a common theoretical base.

This can be demonstrated by the example of zonal locations for household residence and workplace. To see this, let us first simplify notation by denoting V_{ij} as some cell in the macro-level "transition matrix," where i represents a combination of residence zone and workplace (including a pseudo-workplace of not-employed) at time t, and j represents a similar combination (including as pseudo-residence of dying or out-migrating) at time $t + \Delta t$.

In order to clarify the linkage between the micro- and macro-level models, we shall first treat the problem in a relatively abstract, theoretical fashion. Following this, we shall show how, with some relatively simple, practical approximations, this abstract theory can be implemented into a practical means of obtaining aggregate, or macro-level, forecasts from micro-level models.

Theory

At the micro level, we are interested in the behavior of individuals. Whether the underlying structure of people's decision-making process is simultaneous or involves sequential decisions, it is always possible to write the choice model as

$$P\{(r,w,x)_{t+\Delta t} \mid (r,w,x)_t, z_t, z_{t+\Delta t}\}$$

where:

- r is some residence place (as before);
- w is some workplace (as before)
- x is a vector of related household decisions such as auto ownership, mode to work, auto type, etc.;
- z denotes a vector of variables which affect choices of r, w, and x; and as before
- t and $t + \Delta t$ denote time

Now assume that at the micro level, it is possible to characterize workplaces and residences as points in a two-dimensional plane, and let $f_t(r, w, x)$ be the joint density of people defined over choices of residence, workplace, and other decisions at time t. In this notion, $\int_Q f_t(r,x,w)dQ$ is the number of people at time t at residence r with workplace w and making other choices x, summed over all combinations of (r,w,x) in a set Q. Finally let $f(z_{t+\Delta t}, z_t \mid (r,w,x)_t)$ be the joint density of attributes z at times $t + \Delta t$ and t, <u>given</u> a residence, workplace, and other choices at time t.

This conceptual framework allows for the choice of residence and workplace to be related to other decisions (x) which may not be of direct

interest but must nevertheless be incorporated into the analysis. (Section 3.d discusses these choices in greater detail.) Moreover, it is explicitly dynamic but only allows for the first order time lags; effects of decisions or attributes in period $t - \Delta t$ are assumed not to influence choices in $t + \Delta t$ except through their effects on actions in period t.

Within this admittedly cumbersome notational apparatus, we can now write the complete joint density of people making given choices at time t, choices at time $t + \Delta t$, with attributes at t and attributes at $t + \Delta t$ as follows:

$$F = f((r,w,x)_t, (r,w,x)_{t+\Delta t}, z_t, z_{t+\Delta t})$$

$$= P\{(r,w,x)_{t+\Delta t} \mid (r,w,x)_t, z_t, z_{t+\Delta t}\}$$

$$\cdot \; f(z_t \cdot z_{t+\Delta t} \mid (r,w,x)_t) \; \cdot f_t(r,w,x)$$

Note that to achieve this, we have approximated the distribution of residences and jobs as a continuum over a two-dimensional plane, and we have characterized alternative decision bundles by a density defined over that plane. Moreover, we have characterized the distribution of attributes affecting people's decisions as a density.

As a last step in linking the macro and micro level, let us define two sets:

Q_1 = the set of all combinations of r, w and x, consisting of residence points in zone A, all workplaces in zone B and <u>all</u> possible other decisions x.

Q_2 = the set of all combinations of r, w and x consisting of all residence points in zone C, all workplaces in zone D and all possible other decisions x.

Note that the residence and workplace zones include the "pseudo-zones" of not working or leaving the system in the interval t to $t + \Delta t$.

Using this notation, we can now link the macro and micro levels as follows

$$V_{ij} = \int_{Q_1}\int_{Q_2}\int_{Z} F dz dQ_2 dQ_1$$

where Z denotes the space of all possible attribute vectors.

Implementation

Of course, as a practical matter it is unlikely that the needed distributions $f_t(r,w,x)$ and $f(z_{t+\Delta t}, z_t | (r,w,x)_t)$ will be available, and it is still more unlikely that the above integral expression will lead to a closed-form solution for V_{ij}. There is, however, a practical approach that has been used in travel demand analysis to approximate such integrals.

Suppose one wished to forecast V_{ij} from the micro level. Consider a sample of individuals at time t, and let r_t, w_t, x_t and z_t be observed for each observation in the sample. Assume that the sample is randomly drawn.*

*This can readily be relaxed to allow for general stratified sampling, which includes choice-based samples. See Lerman and Manski (1978).

For each observation, the value of $z_{t + \Delta t}$ is also assumed to be known (or at least predictable). In this case, we could also predict the residence, workplace, and other choices x for period $t + \Delta t$ using the choice model. Finally approximate the set of all alternatives by discrete set of points sampled at random the continuum and let Q_1' and Q_2' be the sets of such points belonging to Q_1 and Q_2 respectively. The value

$$\tilde{V}_{ij} = \delta \sum_{Q_1'} \sum_{Q_2'} P\{(r,w,x)_{t + \Delta t} | (r,w,x)_t, z_t, z_{t + \Delta t}\}$$

(where δ is the inverse of the proportion of the population sampled) is then a consistent estimate of V_{ij}. In the statistical sense, $\tilde{V}_{ij}$ converges in probability to V_{ij}. This approach is termed <u>random sample enumeration forecasting</u>, and is described in Chapter 5 and Appendix A.

3.4 Development of a Household-Level Spatial Analysis Model

A. Motivation

The general model framework involves the complex interaction of multiple sectors of activity systems, including the supply and demand aspects of markets for housing, land use, employment, commercial products and industrial outputs. The limited resources currently available for model development clearly preclude the development of a comprehensive transportation/spatial analysis model system. For this reason, a component-oriented model approach is suggested. Current model development efforts can first focus on one crucial aspect of the

system--for example, the need for a behavioral model of household location, employment and related transportation decisions, sensitive to the full set of non-transportation tradeoffs as well as assumptions concerning future changes in technology, resources, and lifestyle.

Changes in inter-regional commodity flows, inputs for production and flows of capital investment funds are exogenous for this phase. It is recognized that the isolation of one component of a larger environment can miss induced effects with respect to other system components. On the other hand, it is crucial that the problems with past attempts at comprehensive models should not be repeated (See Chapter 2 discussion). A specific criticism of all large-scale land use models has been the large number of simplifying assumptions required. It is, therefore, suggested that a behavioral-based model of one major aspect of transportation-societal impacts may yield more insight for long-term policy analysis than yet another attempt at a comprehensive model of all urban change.

The critical nature of consumer residential location decisions come from the fact that urban travel characteristics are very dependent on the spatial distribution of urban activities. Both urban density patterns and trip distance are ultimately affected by the housing type and location choices of individual families. Auto ownership and mode split are very much related to residential location decisions, insofar as the automobile offers a substitute means of achieving accessibility, in place of a location convenient for walking or transit trips. Not only do urban density and distances affect travel demand, but transportation system access could have real effects on urban development.

B. Household Decision Process

Figure 2 illustrates the long-run relationship between housing, employment and transportation decisions made by households.[1] This figure also illustrates the boundaries of our study of the household decision process. It is important to note that the long-run decisions of other actors--producers, developers and regulators, are treated as exogenous in this specific context. This approach is structured to be explicitly dynamic in that the changes in household choices are explicitly represented in terms of an adjustment model.

At any particular point in time, the household's current "state" can change as a result of exogenous events or the aggregate cumulative decisions of other households. The area inside the dashed line represents the actual decisions endogenous to the model framework. These are:

- o adjustment of workplace, or labor force participation
- o choice of workplace location (for new workers and those changing workplaces)
- o adjustment of residence location
- o choice of residential bundle, including housing and auto ownership (given a decision to relocate)
- o choice of mode to work.

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[1] A version of this diagram was originally presented in Transportation Impact Evaluation System, Cambridge Systematics, Inc., 1979.

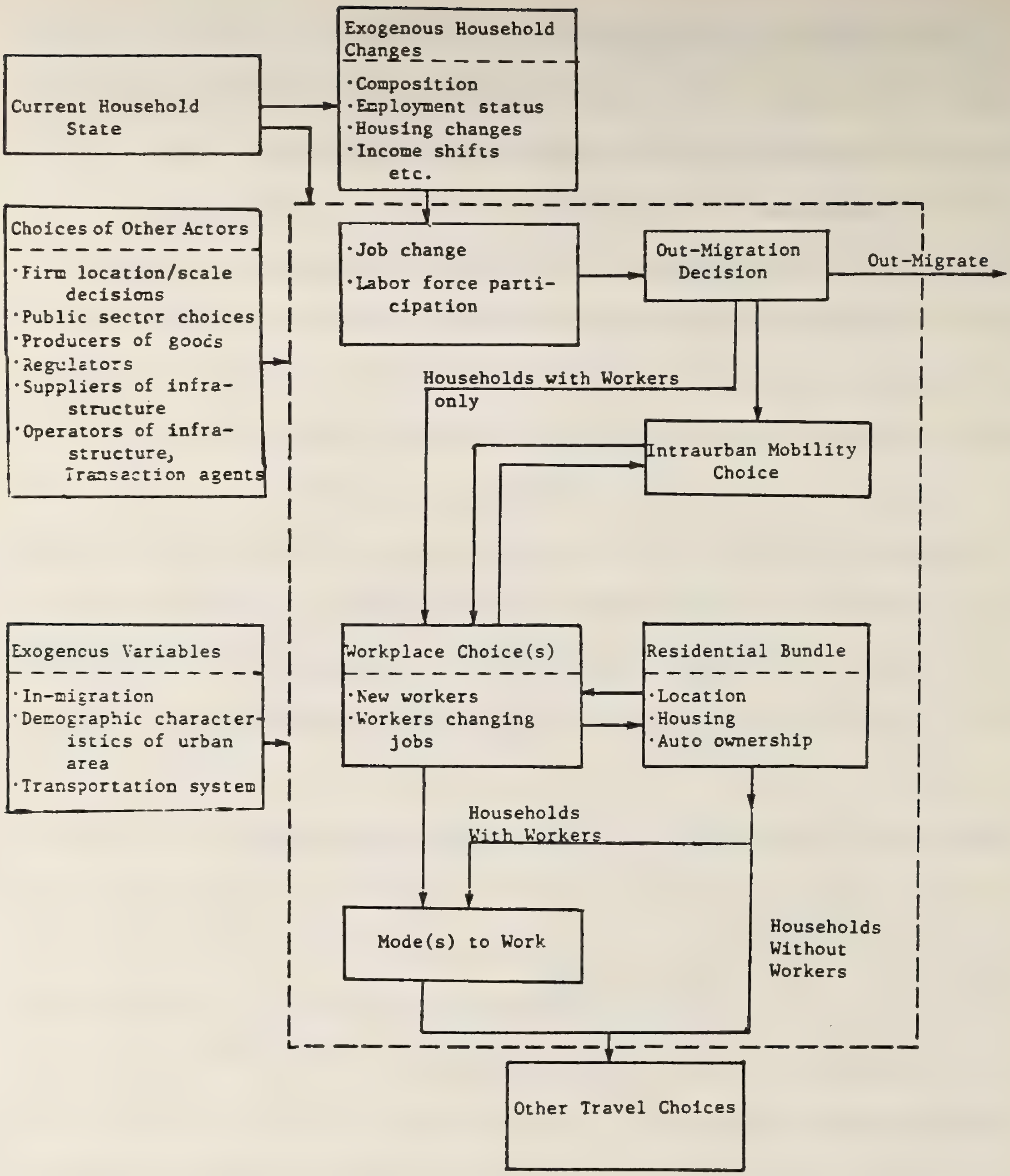

FIGURE 2

Framework for Household Location Decisions

The model "feeds into" another set of models to predict short-run travel choices for non-work trips, including trip frequencies, modes and destinations for various purposes. Conceptually, this model applies at every point in time, though more realistically it would be used for discrete time intervals.

C. Model Structure

It is important to note that there are major feedback loops in the model framework which are not represented in the diagram. In particular, changes in residence and workplace location choices by individual households can, in the long-run forecasting context, lead to shifts in aggregate spatial development patterns. This, in turn, will change the characteristics of locational alternatives for subsequent residence and workplace location decisions.

A second aspect of the model structure concerns the relationships between long-term and short-term decisions. While residence, employment and auto ownership decisions all interact with travel behavior, it is also clear that choices such as location or auto ownership are relatively long term in nature, while many travel decisions are highly variable. For this reason, one would reasonably expect that travel behavior choices are conditioned on location and auto ownership decisions rather than vice versa. A nested or recursive model system that incorporates a sequential structure with feedback can appropriately represent such a situation.

A recursive (or nested) model structure allows for a relatively general representation of decision behavior. In the context of multinomial logit, nested models have as a special case simultaneous choice models; however, they additionally permit choice behavior which allows for at least some relaxation of the assumptions inherent in simultaneous logit models.[1] The key to these models lies in the feedback from "lower stage" models to upper stage ones. Thus, while the heavy arrows in Figure 2 indicate the direction of assumed conditionality in this model structure, there is implicit the concept that each decision is affected by the household's expectations on lower level decisions. The use of "logsums" or "inclusive prices" as a form of feedback between the model stages is further discussed in Ben-Akiva and Lerman (1978), McFadden (1978), and Neels and Cheslow (1979).

D. Simulation Framework

There is a range of variables that are defined as exogenous to the previously described household decision process and model structure. This occurs not only because the analysis problem must have reasonably finite boundaries, but also because there is a tremendous uncertainty about a range of other variables, all of which can be major factors in location and housing choice. These include:

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[1]Specifically, a nested structure allows for correlation between utilities of various choices which share a common "branch" of a decision tree, while a simultaneous structure requires independence of the utilities of all potential choices.

- o future real income and its distribution
- o labor force participation
- o housing construction costs
- o energy costs and other natural resource costs
- o future technology for communications and travel
- o future rates of household formation, marriage and divorce
- o future taxation and income redistribution policies
- o future differences in regional growth rates.

In order to capture these uncertainties, we propose to represent each scenario by a longitudinal sample of households whose characteristics are reflective of the assumptions in the scenario. This sample of households will be generated by simulating changes in households' characteristics via a series of Monte Carlo transitions. Each time period (probably a year), potential changes (e.g., death, divorce, or marriage) for every household in the sample will be simulated from pre-specific probability distributions. At the end of this time period, each household will have undergone complete set of demographic changes which will potentially alter its significant characteristics. In the probabilistic sense, the sample of households each period will be used to represent the complete population. Various scenarios will be represented by simply altering the transition rules and transformation probabilities (see Figure 3).

For any particular scenario, changes may be made to the base case rate for population transition rates, disposable income, costs of goods and services, travel time functions, etc. A sample of households for the base year would then be simulated through the next N years (where N was the time horizon of the study), and in each year the sample would age and undergo various demographic transitions on a stochastic basis. This

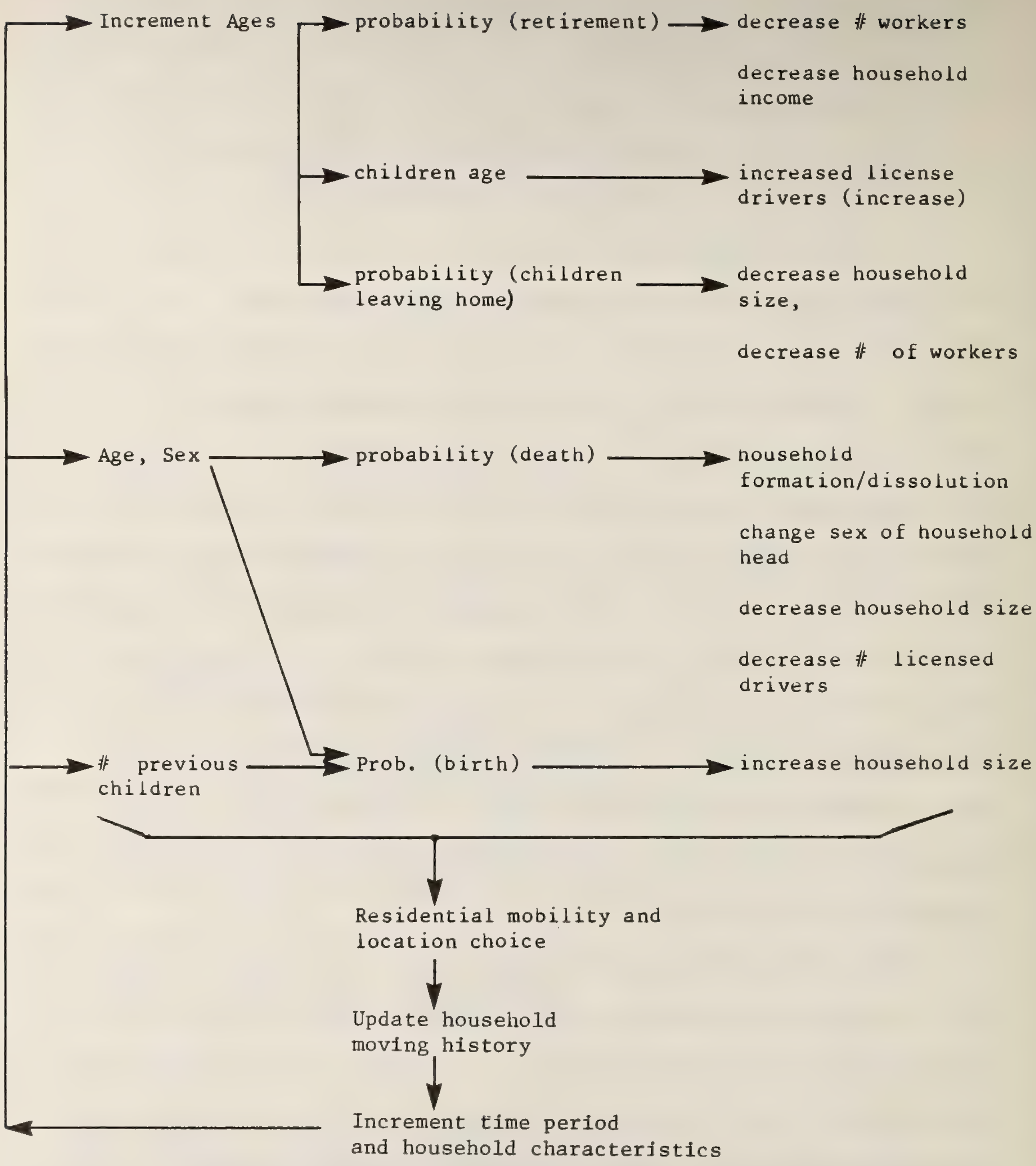

FIGURE 3

Micro-Analysis Updating Procedure

approach is directly analogous to one adopted in the DYNASIM microsimulation model (see Orcutt, et al., 1976). The output of this process is a longitudinal sample of households, where each household (except those that dissolve or are created in the simulated period) is observed at time intervals.

4. CONCEPTUAL FRAMEWORK: MAJOR ISSUES FOR THE DEVELOPMENT OF SCENARIOS

4.1 Introduction

Changes in American society over the next 30 years can significantly alter current patterns of travel behavior and housing choice. Cambridge Systematics' approach to the analysis of travel and housing choice behavior is explicitly designed to forecast the effect of future societal change. The conceptual framework for modelling and long-range forecasting is specifically organized to be responsive to five major classes of exogenous changes affecting economic and lifestyle patterns:

1. changing demographic patterns
2. economic implications of changing income and employment characteristics
3. future energy costs
4. rising land and housing costs
5. major technology changes.

A major focus of the study approach is the construction of future scenarios, which represent the range of conditions likely to influence travel and housing decisions over the next 30 years. Scenarios will consist of projections of future conditions, which will be incorporated into the forecasting framework as partially or fully exogenous variables. The range of potential scenarios is discussed below, in terms of the conceptual relationship between scenario forecasts and the

modelling of travel and housing choice decisions. In order to construct realistic scenarios, the expected magnitude of future shifts in the five dimensions of change are also discussed.

4.2 Demographic Patterns

Population patterns constitute a key determinant of the market for both transportation services and housing. Over the next 30 years, the demand for various types of transportation and housing will depend not only on the size of the population, but also on such factors as age and lifecycle distribution, population distribution by region, and the number and composition of households.

The market for all types of transportation services and housing can be expected to grow as the population increases. Census projections of the US population in the year 2010 range from 251 million to 315 million.[1] Obviously, the estimated impact of population growth on the demand for transportation and housing can vary widely, given the broad range of population projections. However, for the purpose of forecasting, aggregate population growth alone is a poor measure of the change in demographic characteristics, as suggested above. The volume and type of transportation services and housing consumed per person depend on the age distribution of the population and household characteristics. Moreover, data will be most useful for forecasting when disaggregated to the regional or metropolitan-area level.

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[1]US Bureau of the Census. Current Population Reports, Population Characteristics, Series P-20, #285, pp. 6-8, October, 1975.

Over the next 30 years, the US population is projected to change not only with respect to total numbers, but also in terms of age and life-cycle composition. Specifically, the age distribution will be shifted upwards, as the post-WWII baby boom generation ages. For example, between the years 1976 and 2010, the proportion of the adult population between 18 and 44 years old will have declined 6.5 percent, while the proportion of adults 45 to 59 and 60 or more years of age will have increased by 5.2 percent and 1.8 percent, respectively. This projected change has potentially significant implications regarding travel behavior and housing choice, when viewed in combination with data on projected household composition. Trip frequencies, distances, and purposes all tend to vary across age/lifecycle categories, as do housing type and location choices. Generally, single adults (predominantly the young and the elderly) tend to live closer to the central city and to travel shorter distances. They also tend to live in apartments and other relatively small housing units. Frequency of travel is significantly lower among persons over the age of 60, as compared to younger adults. This decline is due primarily to reductions in work-trip travel among persons who retire. Hence, the rate of per-person travel and the demand for housing are likely to change over the next 30 years, as a result of changes in the age/lifecycle composition of the population.

Another important demographic factor which is likely to affect transportation and housing markets is change in the number and

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Based on Census Series II projections, see <u>Projections of Automobile Use and Ownership Based on Lifestyle Factors</u>, Norman P. Hummon et al., 1977.

characteristics of households. The age distribution of households will change over the next 30 years in accordance with changes in the age distribution of the population. In addition, the Census projects that increases in the number of households over the next 30 years will exceed overall population growth by a substantial margin. Among persons aged 18-44 and 45-59, the percentage of the population who are heads of households will have increased between 1976 and 2010 by 12 percent and 1.9 percent, respectively, while the percentage of household heads will have decreased by only .7 percent among persons 60 years of age and older. The increase in the percentage of household heads among young adults is due to projected increases in the proportion of single family households, as marriage rates decline and divorce rates increase. The relatively small decrease in household headship among persons above the age of 60 is a result of reduced mortality rates.[1] The overall growth in the number of households will generate increased travel frequencies and demand for housing units.

4.3 Economic Conditions

The two major economic variables, apart from energy and housing prices, likely to have a direct impact on future travel behavior and housing choice are real (constant dollar) disposable income and labor force participation. Disposable personal income (DPI), which includes income after taxes and social insurance payments, represents the amount of money people have for personal expenditures, including automobiles,

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[1]See also Sternlieb and Hughes, Current Population Trends in the United States, Wiley-Interscience, New York.

travel, and housing. Change in personal income represents a particularly important input to the forecasting of transportation/housing choice when viewed in combination with data on energy and housing prices. Assuming that the ratio of DPI to Gross National Product remains constant at .71 over the next 30 years, constant dollar DPI should more than double by the year 2010. This estimate is based on an assumed annual growth rate in GNP of 3.5 percent, which is roughly equivalent to the average annual growth rate since 1960. Alternative projections of the growth in GNP, or the ratio of DPI to GNP, could significantly affect forecasts of personal expenditures on transportation services and housing.[1]

Labor force participation is relevant to the direct analysis of travel, in that changes in employment levels are likely to result in changes in the frequency of work-related travel and concomitant changes in travel for other purposes, as the amount of time available for other activities declines. In recent years, the civilian labor force has grown more rapidly than the population, due primarily to increases in the participation rates among women. According to Census projections, labor force participation among men is expected to remain nearly constant between now and 1990,[2] while the percentage of women in the labor force is forecast to increase by 0.3-0.5 percent annually.

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[1]See also, National Planning Association, Basic Maps of the US Economy: 1967-1990, Washington, DC 1979.

[2]US Department of Labor, Bureau of Labor Statistics, New Labor Force Projections to 1990, Special Labor Force Report (Washington,D.C.: US Government Printing Office, 1977).

4.4 Energy Prices

A complex set of factors will determine changes in energy prices over the next 30 years. On the supply side are such variables as the ultimate size of oil and natural gas reserves, OPEC policy, and the rate of development of alternative energy sources (e.g., shale oil extraction, coal gasification, solar power, windmills, and nuclear breeder reactors). On the demand side, there is the question of the magnitude of energy savings which can be achieved through conservation in transportation, space heating, manufacturing, and other areas. The uncertainty associated with the forecasting of long-term energy prices is illustrated by the fact that in the Project Independence report, prepared by the former Federal Energy Administration[1] in 1974, it was assumed that the price of crude oil would reach a maximum of $15 per barrel by 1985, while the actual price per barrel was $19.61 in December, 1979.[2]

Energy prices represent one of the most critical determinants of future travel behavior and housing choice decisions. The effects of energy price increases far in excess of traditional expectations are presently unknown. Responses to rapidly rising energy costs could take the form of fundamental change in both the supply of and demand for transportation services and housing.

Potential impacts on travel demand include reduced travel frequencies and distances, and changes in transportation mode. Increased

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[1]Now incorporated into the Department of Energy.

[2]Average oil price estimate is based on $28 per barrel price of OPEC oil and $13.22 price for domestic price-controlled oil.

cost of travel may also influence the demand for housing, as reflected in an increased preference for residences located close to centers of employment and other activity. Energy costs may also influence the demand among consumers for particular types of housing, resulting perhaps in a shift towards smaller residential units.

Changes in transportation supply may take the form of improved and expanded public transit services and/or more fuel efficient private vehicles. In response to shifts in consumer demand, the housing stock may consist of a higher proportion of smaller units, and increased residential densities. The supply response to increased energy prices, particularly in the case of transportation services, is highly dependent on potential advances in technology. This issue is discussed later in this chapter.

4.5 Housing Costs

Increases in housing prices throughout the second half of the 1970's generally exceeded the overall rate of inflation. Housing-type choice decisions in the future will obviously be heavily influenced by the price of housing, relative to other commodities. Apart from energy, the two principal variables likely to have a major long-term effect on housing prices are land values and construction costs.

Since the quantity of land available for construction is relatively fixed, land values vary principally as a function of demand. The key determinants of aggregate demand for developable land are the size and composition of the population, income, economic growth, and costs of transportation, heating, building and maintenance. Construction costs, which represents a major component of total housing costs, are a function

of labor costs and productivity, as well as the price of building material. Price increases in the latter category have often outpaced the general inflation rate over the last several years. Potential resource shortages over the next 30 years could result in substantial increases in construction costs, unless there are major advances in prefabrication and new construction technologies.

4.6 Technology

One of the major questions concerning the future of both transportation and housing is the nature and extent of technological change which will occur over the next 30 years. Particularly in the case of transportation, there is a likelihood that the impacts of technological developments may overshadow any of the issues previously identified. Residential location decisions would be directly affected by any significant developments in transportation technology, since travel time and costs have a major influence on residential location and housing choices.

Technological advances may range from relatively simple increases in the fuel economy of private automobiles to major changes in the role of transportation in society, such as would result from the substitution of communications for transportation. The impacts of technical development on travel behavior and housing choice could vary widely, dependong on the nature of the change in technology. That, in turn, depends on the extent of federal investment in new technology.[1]

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[1]See National Transportation Policy Study Commission, National Transportation Policies through the Year 2000, 1979.

The most important potential changes in transportation technology, from the standpoint of travel behavior and housing choice decisions, are those which would reduce fuel costs. While increased energy prices would result in reduced travel, possibly a shift to alternative modes and increased preference for centrally located housing, the reduction of fuel costs for private vehicles through technological improvements could counter these trends.

Improvements in the fuel economy of internal combustion engines are among the more probable technological advances which could influence travel behavior and housing choice. The 1985 EPA fleet-wide fuel economy standards for new cars is 27.5 mpg. The EPA estimates that fuel consumption for the entire automobile fleet will average 19.4 mpg in that year, and 24.6 mpg in 2000, based on the 27.5 mpg standard and current turnover rates in the automobile market. However, it appears likely that further improvements in fuel economy are possible through the application of several technologies which are currently in the development stage. The DOE is currently sponsoring research related to the development of gas turbine and Stirling engines. The use of lighter, composite materials in vehicle construction, including reinforced plastics, is also likely to result in increased fuel economy, although the application of these materials will require significant modifications of current production practices.

Another potentially significant new technology is the electric vehicle. As the cost of petroleum increases, the economics of the electric vehicle relative to automobiles with internal combustion engines

will become increasingly more attractive. At present, one of the principal obstacles to the marketing of electric vehicles is their limited travel range. Electric vehicles are currently capable of travelling 50 miles between battery rechargings. It is estimated that a vehicle with this capability could be used for approximately 92 percent of all private vehicle trips. The DOE expects a 100 percent increase in the range of electric vehicles over the next few years, which would extend the capabilities of the electric vehicle to cover 98 percent of all automobile trips. Acceptance of the electric vehicle is currently limited by the fact that people generally purchase automobiles which satisfy their <u>maximum</u> travel distance requirements, (e.g., for long vacations), as opposed to the requirements associated with their most frequent vehicle use. Although conservative estimates place the number of electric vehicles in use by 1990 at approximately 2 million (which is relatively insignificant in comparison to the total vehicle fleet now over 120 million), potential market penetration by the year 2010 could be significantly greater, particularly if petroleum prices continue to escalate.

Continued advances in the development of communication technology could result in fairly widespread substitution of communications services for transportation. The audio, visual and data communication services of the future will closely approximate the communication capacity of today's face-to-face meeting. The next generation of communication services will link the memory, analysis and display capacity of computers in broadband networks. These networks will have the ability to transmit data,

graphics and moving video displays from point to point, thereby greatly enhancing the volume and quality of electronic interaction in the 1980's and beyond. These technology advances are particularly relevant for employment in the banking and finance fields. It has been estimated that more than 20 percent of current work trips could be replaced through the use of existing communications technology.[1] This proportion is likely to increase if, as expected, the percentage of white collar workers increases. Moreover, further substitution of communications for travel is possible in the case of shopping, education, and recreation trip purposes, as a result of advances in the application of cable TV technology.

The widespread substitution of communications for travel would reduce the importance of transportation as a determinant of residential location choice. Specifically, if travel distances no longer represented a significant constraint on residential location choice, the relative influence of other factors, (e.g., environmental amenities, land availability) would increase. The most likely result would be the increased dispersal of the population in lower density residential settings, and the further decline of the cities as a focus for

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[1]David W. Jones, Jr., Must We Travel? The Potential of Communications as a Substitute for Urban Travel, Institute for Communications Research, Stanford University, 1973. See also, Jack Nilles, et al. The Telecommunications-Transportation Tradeoff: Options for Tomorrow, Center for Urban Policy Research, Rutgers University, 1976.

transportation, employment, and other activity. This is particularly true since a large proportion of the occupations susceptible to substitution are presently based in central cities.

5. CONCEPTUAL FRAMEWORK: FORECASTING PROCEDURES

The linkage of micro level (disaggregate) models to macro level forecasts is usually accomplished by the "sample enumeration" technique. This forecasting method is now used as part of a travel demand forecasting system developed at MIT (Watanatada, 1977), and is applied for housing and location forecasting in the current version of the NBER Urban Simulation (Kain et al., 1976). It is also being used by Cambridge Systematics in a travel model developed by Lerman et al. (1979) and has more recently been expanded to employment location as well as mode choice and other travel destination (Cambridge Systematics, 1979). It represents a computationally efficient way of estimating population aggregates by using disaggregate models. In a sense, it is a type of Monte Carlo integration where the "points" drawn are actually observations from the population rather than values from a known probability distribution. The theory of sample enumeration, the use of Monte Carlo methods in sample enumeration forecasting, and the practical issues in implementing such procedures are summarized below. To illustrate the practical application of this technique, the NBER Urban Simulation model forecasting technique is described. Methods of forecasting with an equilibration of demand and supply are then presented.

5.1 Theory of Sample Enumeration

Let us assume that we have a choice model explaining some behavior of interest (e.g., residential location, housing choice, etc.). Let $P(i|z_n)$ denote the probability that decision-maker n (with corresponding attributes z_n) selects alternative i.* (This probability might be modelled with multinomial logit or any other discrete choice model.) The problem

*The term attributes is used here to include characteristics of the individual (e.g., income, age, or sex) and characteristics of the alternatives that the individual faces (e.g., travel times and costs, housing prices, or accessibility to a workplace).

of interest is to forecast the expected share of some group of individuals selecting alternative i. The group might consist of all residents of a city, the residents of a traffic analysis zone, or members of a particular socioeconomic group. The alternative i might be whether or not to move in a year, how many automobiles to own, whether and where to work, or which mode to use to work.

Obviously, if we knew the attributes of <u>all</u> the individuals in the population of interest and the attributes of <u>all</u> the alternatives each person faced, the expected share of the group choosing alternative i, Q(i) would simply be:

$$Q(i) = \frac{1}{N} \sum_{n=1}^{N} P(i|z_n), \tag{1}$$

where N is the size of the relevant population.

As a practical matter, the attributes of every single member of the population are rarely (if ever) available; thus, we need some means of either estimating or approximating Q(i). While Appendix B to this report summarizes four such procedures, one approach has proven to be widely applicable to diverse problems. This approach assumes the availability of a sample of the total population. Each observation in the sample is used to "represent" some fraction of the complete population.

In the simplest case, the sample is random. If the sample is of size N*, then each observation "represents" $\frac{N}{N*}$ individuals in the sample. More formally, the estimator $\hat{Q}(i)$ defined as

$$\hat{Q}(i) = \frac{1}{N*} \sum_{n=1}^{N*} P(i|z_n) \tag{2}$$

provides an unbiased estimate of $Q(i)$. ($\hat{Q}(i)$ is simply the average probability of choosing i for observations in the sample.)

Lerman and Manski (1979) discuss sample enumeration forecasting with a more complicated sample design. Suppose that we first stratify the population into subgroups, and then sample randomly from each subgroup. In this case, subgroups can be defined along socioeconomic attributes, attributes of alternatives or actual choices made. (An example of this last type of stratification is a sample of residents from a given traffic zone. Such a sample would be drawn randomly from the subgroup of households that choose the particular zone.) A sample drawn in this fashion is termed a generalized stratified sample.

The procedure for forecasting the aggregate share choosing some alternative i with a generalized stratified sample is only marginally more complicated than with a random sample.* If we define B to be the number of strata and N_b to be the size of the sample drawn from the b-th stratum, we can first estimate the share of the b-th stratum choosing i, $Q(i|b)$, as

$$\hat{Q}(i|b) = \frac{1}{N_b} \sum_{n=1}^{N_b} P(i|z_{nb}) \tag{3}$$

where z_{nb} are the attributes for the n-th decision-maker in the b-th stratum. As a second step, we can then weight the estimates of each stratum's expected share by its relative size. If F_b denotes the share of the entire population in stratum b, then

$$\hat{Q}(i) = \sum_{b=1}^{B} \hat{Q}(i|b)F_b \tag{4}$$

*A random sample is simply a special case of a generalized stratified sample in which there is only one stratum.

Lerman and Manski (1979) discuss ways of estimating F_b. The simplest is obviously to use tabulations from a census or other large-scale survey.

It should be noted that generalized stratified samples can be developed by combining diverse surveys. For example, Eagan (1976) combined a transit on-board survey and a roadside interview to develop a stratified sample for modelling mode choice. It is also possible to use the same sample collected for the original purpose of estimating models to perform sample enumeration forecasting. In another approach, Lerman, *et al*. (1977), McFadden, *et al*. (1977), and Watanatada (1977) have used samples that were synthesized from Census and other published tabulations by making a series of somewhat *ad hoc* assumptions about how various attributes are distributed in the population. Other strategies have included direct telephone surveys and various combinations of the above approaches.

5.2 Use of Monte Carlo Techniques With Sample Enumeration*

Just as it is possible to sample individuals from a population, it is possible to sample from the predicted outcomes of that population's choices. For example, suppose an individual makes a sequence of decisions over time as to whether or not he/she should change his/her residence. If a choice is made each year over 20 years, the number of possible sequences is 2^{20}, or 1,048,576 possible outcomes. Predicting the probabilities associated with all these possible sequences of binary relocation choices is obviously a cumbersome task; if other choices such as

*See Lerman and Manski (1980) for a theoretical treatment of the statistical issues in the use of Monte Carlo simulation for predicting choice behavior.

where to move, the type of house to rent or buy, and whether or not to change jobs are added, the number of possibilities quickly makes prediction for each alternative computationally infeasible.

Fortunately, it is possible to sample from the outcome of the choice process at each stage. Following the example of residential relocation, suppose in the first year the probability of moving is P_1 (with the corresponding probability of not moving being $1-P_1$). We could simply draw a uniformly distributed random number between 0 and 1, and if the value is less than or equal to P_1, assign that person to the "movers" category. In the next year, the same individual would be treated as having moved in the prior year, and the probability of his/her moving again would be predicted conditional on that prior move. A similar Monte Carlo experiment would be conducted, and the person's simulated moving behavior would be updated. This procedure would continue for all twenty years.

After performing this simulation for a sample of individuals, one can then simply estimate Q(i) as the share of people having "chosen" (in the simulation) a particular alternative.*

5.3 Practical Potential of Sample Enumeration

The potential practical uses of sample enumeration coupled with Monte Carlo simulation are enormous, particularly as applied to sequences of

*The precision of such estimates (as measured by the standard error of the estimated Q(i)) varies inversely with the square root of the number of simulations. The standard error of the estimated shares will tend to be smallest when the true choice probabilities are near one.

decisions over time. For example, it is possible to update each person's or household's socioeconomic characteristics at each time interval before predicting the relevant choice probabilities. Aging, life cycle changes, income shifts, deaths, household dissolution, and other demographic shifts can be "built into" the simulation by providing transition probabilities for the various possible events.

In a sense, the sample can be treated as a cohort with constantly changing characteristics governed by actuarial tables and other transition tables. New households or individuals can be introduced with known characteristics as existing households dissolve or out-migrate. This type of procedure is embedded within the National Bureau of Economic Research Urban Simulation Model (Kain et al., 1976). On a regional scale, Nagin and Lerman (1979) have outlined how a general housing model (to be used as part of a residential energy demand model system) could be built by coupling sample enumeration with Monte Carlo sampling.

Watanatada (1977) has added further sophistication to this procedure in an analysis of destination choice by sampling from the alternative destinations so as to reduce the computation associated with predicting the choice probabilities for each sampled individual. Lerman and Manski (1979a) also discuss the use of Monte Carlo procedures for estimating choice models as well as forecasting with them.

5.4 Summary of Relative Merits of Sample Enumeration

In summary, sample enumeration offers the following potential advantages:

(1) It yields a consistent estimate of the aggregate shares Q(i) rather than an approximation of unknown quality; further precision can be gained with increased sample size. This allows for a great deal of flexibility for potential users of the model in that they can regulate the tradeoff between computation requirements and precision quite easily.

(2) Sample enumeration procedures allow for easy representation of policies. For any particular forecast, the policy need only be represented by a change in some values of the independent variables and some criteria regarding who in the population will be affected. Thus, policies such as providing housing subsidies to a particular income group or residents in specific types of housing are easily translated into runs of the model.

(3) It is easy to summarize the impacts of various policies on different socioeconomic groups; all one need do is tabulate the choices of the relevant subpopulation.

(4) Sample enumeration procedures do not make any assumptions about the distribution of attributes in the population of interest.

(5) Once implemented, sample enumeration forecasting models can easily be upgraded without major programming modifications. For example, if a submodel is changed to include a new variable, that variable need only be in the sample.

(6) Sample enumeration procedures are well suited for use in dynamic models. In each period, the characteristics of each observation in the

sample can be updated to reflect aging of the household, changes in household size (perhaps by Monte Carlo simulation), etc. Each observation's prior choices can also be maintained for as many periods as required by the dynamic model structure to forecast the future periods. This can be extremely awkward in the other methods since prior decisions have to be maintained in potentially large contingency tables (along with the other attributes) or maintained as means and variance-covariance matrices.

This should not suggest, however, that sample enumeration procedures (with or without Monte Carlo simulation) are not without potential shortcomings. As with any other aggregate forecasting technique, the predicted aggregate shares are estimates, and they are consequently subject to the usual random variations from sample to sample. As with any other aggregate forecasting technique, the parameters of the underlying choice model are themselves estimates, and are consequently another source of randomness. Furthermore, when forecasts are segmented for a large number of socioeconomic or geographic groups, the subsamples within each group may be quite small, and the precision of each forecast may consequently be very low.

5.5 An Application of Sample Enumeration Forecasting

The NBER Urban Simulation Model is of interest since it operationalizes a version of the random sample enumeration approach. Unlike the 1972 version, the newer model does not maintain tables of households, where they work, where they live, etc. Rather, the model has been designed to maintain what is termed the "Basic List," a random sample of housing units (identified by zone and structure type) and the residents of each unit, each of which has a workplace as well as demographic characteristics. This list is changed over time as the model is executed.

At each time period (typically a year), the model performs a series of procedures on the Basic List. A total of 17 behavioral submodels operate on the Basic List or on temporary lists generated by other submodels. These 17 submodels involve either shifts in demand, supply, or in the housing market. For example, on the demand side, households in-migrate and out-migrate, workers change jobs, households decide whether or not to move, and if they move they choose a new housing type. On the supply side, new employment consumes available land, new housing units are built, and existing units are converted to other uses. In the market sector, households seeking housing units are allocated to the available stock through a market clearing mechanism, and new prices are established.

The use of sample enumeration forecasting can perhaps be illustrated by tracing through the entire demand side of the NBER model.* As a preliminary step at each time period, the user inputs the changes in the

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*Note that the supply side submodels are executed in parallel with the demand side, but only demand submodels are summarized here.

level and composition of exogenous (or basic) employment for each work-zone. This employment does not include retailing or other population-serving employment, which is forecast endogenously in the second step. These employment changes are then converted into the change in jobs by industry and occupation at each zone.

After these employment changes are computed, a series of submodels operate on the Basic List. These are executed in sequence for each household on the list. First, the model simulates demographic change (aging of household head, changes in family size, and changes in family income). These changes are generated by Monte Carlo simulation based on user-supplied contingency tables. Next, changes in jobs are simulated; the household head either keeps his/her job or seeks a new one. If a new one is sought, a submodel simulating the search for employment is invoked.

The third relevant, demand side operation on the Basic List simulates moving vehavior; this submodel determines (in the probabilistic sense) which households move and which remain in their current unit. Movers are added to a temporary list of households seeking units, and the prior housing is made available for other households.

The fourth submodel generates new households (by socioeconomic group). These households are added to those seeking housing, and their characteristics are assigned to reflect aggregate, metropolitan level forecasts.

The next two demand submodels simulate choice of housing type and tenure (rent vs. owned). These submodels predict choice probabilities, and as with the other submodels, a Monte Carlo simulation is used to assign the household to a specific category.

5.6 Procedures for Making Forecasts with Supply Constraints

It is recognized that forecasts of future patterns of spatial distribution must account for the fact that at each time period the supply of housing and employment opportunities is for all practical purposes fixed. Thus, after the disaggregate model is developed, it must ultimately be embedded into an equilibrium framework for useful policy-relevant forecasts to be made. Recent work in this area has suggested some fruitful approaches, discussed below:

Anas (1978) has considered this problem at the simple theoretical level. He explores the role of price variables in a free market system. The logit choice probabilities he uses are for a single population group with fixed workplaces, and only housing and location choices are to be solved for. The price of a housing bundle is assumed to enter each utility function, and different sets of prices consequently produce different patterns of location. He shows that in general the pattern of prices that will be consistent with exogenously set supply constraints is not unique. Anas proposes a heuristic algorithm to select a likely equilibrium set of prices by attempting to reflect how owners of housing might respond to market conditions of oversupply or excess demand.

This same problem is identified by Worms (1976) in an attempt to embed a set of disaggregate location, housing, auto ownership and mode to work models developed by Lerman (1975) into a simplified version

of the NBER Urban Simulation Model: In this case, there are a number of different population groups, each seeking housing. Worms develops a market clearing algorithm which, while somewhat different from Anas', is also heuristic in nature.

In quite a different context, Florian and Los (1978) have also considered a problem which can be interpreted as market clearing with disaggregate choice models. The specific application is when a single class of commuters must select among alternate parking lots along a transit route. Each lot has a fixed supply of parking places, C_j, and for each origin (all travellers are assumed to be travelling downtown) the total generalized cost (or utility) is assumed to consist of the cost of going to a parking lot, the cost of parking, and the line-haul cost. Prices are assumed (at least in a single period) to be fixed.

The most significant result of their work is that if the choice process is logit, then there exists a constrained optimization problem which, when solved, yields an equilibrium solution to the choice problem. Moreover, this solution is unique, and available computational methods (most notably the Frank-Wolfe algorithm) can solve the problem quite efficiently. Finally, the dual variables of this problem have a direct interpretation as shadow prices for the scarce resource (in this case, parking spots).

The operation of this approach can best be illustrated by an example in which workplace is assumed fixed.* Let $P_r(k|\ell)$ be the probability residence zone k is selected by someone working at ℓ. Let N_ℓ be the

*The extension to workplace and residence choice is straightworward; however, the manner in which dynamic effects would be incorporated into this approach is still unclear.

number of people working at ℓ who are seeking housing in the period, and let N_k be the total stock of units available in the time period. Let $v_{k\ell}$ be the average utility (including transportation and housing costs) of someone working at ℓ selecting residence zone k. Suppose the probability of k being selected is given by

$$P\,(k|\ell) = \frac{e^{v_{k\ell}}}{\sum_k v}$$

One can readily show that the problem of assigning individuals to the residence zones can be expressed as the solution to the following mathematical program:

$$\text{Max} \quad P\,(k|\ell)\ell nP\,(k|\ell) - v_{ij}P(k|\ell)$$

$$\begin{array}{llll} \text{Subject to} & P(k|\ell) \geq 0 & & \text{for all i,j} \\ & \sum_k P(k|\ell) = 1 & & \text{for all i} \\ & \sum_\ell N_\ell P(k|\ell) \leq N_k & & \text{for all j} \end{array}$$

where the solution is given as a set of $P(k|\ell)$. The dual variables associated with the last group of constraints are shadow prices for the housing units in the corresponding locations and are potentially useful as price indicators for the next period.

Other work by Sheffi (1978) and Daganzo (1977) has extended the use of optimization to solve what they term "stochastic user equilibrium" problems. In particular, they show that appropriate objective functions

(i.e., objective functions which, when maximized subject to approximate constraints on supply, yield solutions consistent with probabilistic choice models) exist for a broad class of choice models.

6. PROPOSED ANALYSIS

The preceding chapters presented a general model framework for urban spatial analysis. This chapter applies that micro-behavioral model framework to construct a specific set of structural equations for application to the analysis of long-run residential location shifts and associated travel changes in metropolitan areas. Data sources for estimation of parameters and validating the proposed approach are then discussed, and scenarios for applying the models are described.

6.1 Outline of the Proposed Model

The proposed study addresses the spatial patterns of population residence and their relationship to employment locations in urban areas. It is motivated by the broad policy implications of future land use patterns, and a belief that future residential location may be best understood in a dynamic framework that focuses on changes from current patterns brought about by individual moving decisions.

The basis of the location choice model is the assumption that, within a given urban area at any given time individuals face a finite set of alternative residence and employment locations. A key aspect is the dynamic nature of spatial location, in which only the marginal change in location patterns is estimated. Since location choice is estimated only for recent movers, problems of households in long-term housing consumption disequilibria that nevertheless do not move are eliminated.

A second purpose of this spatial location modelling is to include as independent variables a wider range of spatial characteristics. The specifications of factors in location demand are expanded beyond economic considerations to include estimates of the effect of crime, neighborhood land use and demographic composition, as well as search distances, on the location choice of movers.

The proposed model system is outlined in Figure 1. It is expressed in terms of a nested multinomial logit in this section. The nested logit is a well-understood sequential-recursive model structure. In theory, other functional forms could be used, as long as they allow a sequential model in which the probability of a given decision is sensitive to the conditional expected probabilities of subsequent decisions in the sequence.

The submodels in a nested logit model system are estimated in an order reversed from the sequence in which predictions are made. In order of prediction, the model system can be expressed as follows:

Define: Choices:

- s = move/stay status
- r = residential location (R = set of all r)
- h = housing type (H = set of all h)
- a = auto ownership level (A = set of all a)
- m = mode of travel (M = set of all m)
- w = workplace location (W = set of all w)
- d = destination for non-work trip (D = set of all d)
- f = frequency of non-work trip (F = set of all possible f)

Terms:

- β = a vector of coefficients
- X = a vector of independent variables for a particular choice
- LS( ) = the "logsum", or accessibility from another logit model
- $\exp(x) = e^x$

A. Residential Mobility Model

$$\mathrm{Prob}(s{=}\mathrm{move}) = \frac{\exp(V_s)}{\exp(V_s) + 1}$$

where:

$$V_s = \beta_s X_s + \beta_1 \mathrm{LS}(\beta)$$

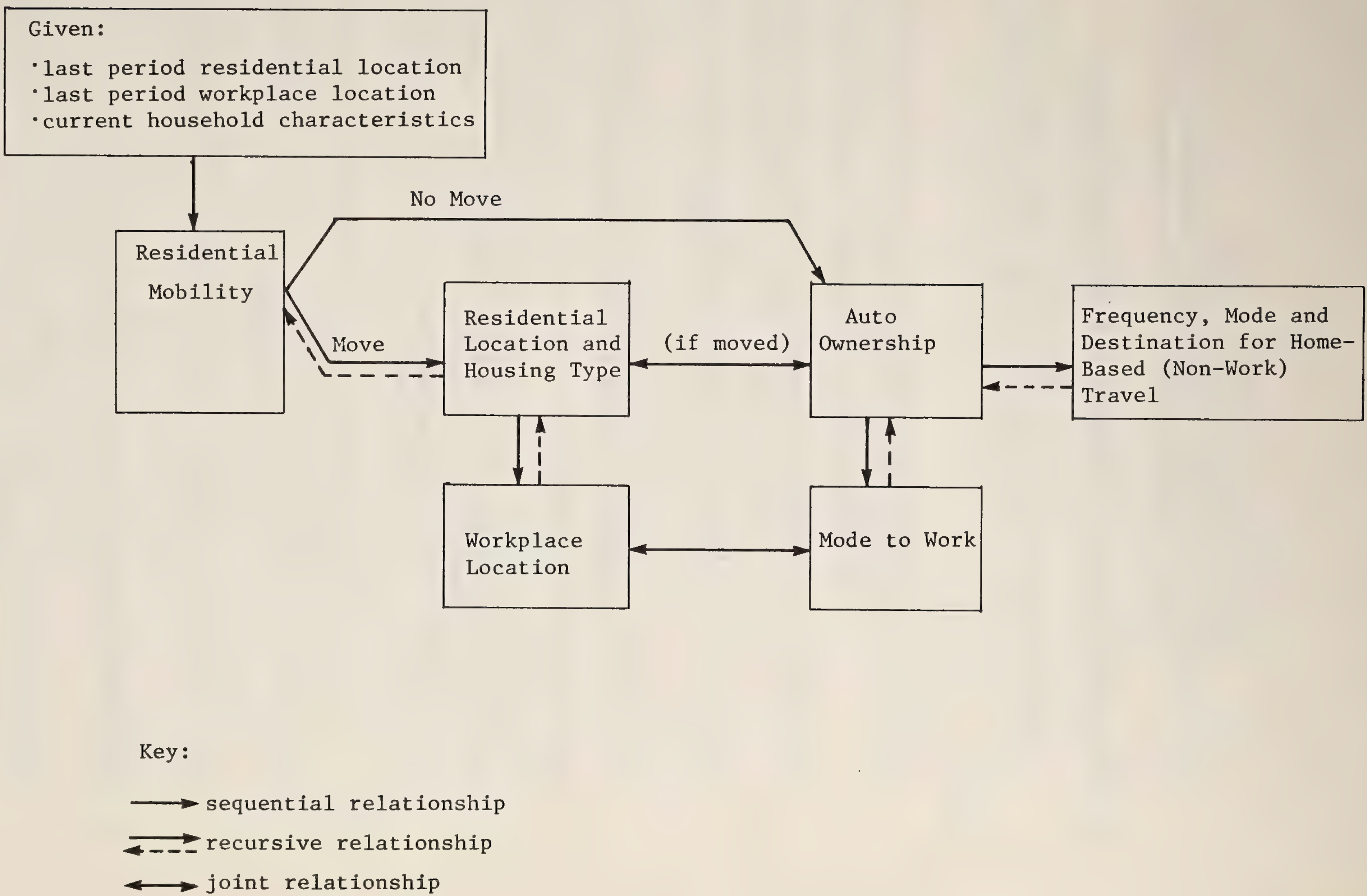
and $\mathrm{LS}(\beta)$ = attraction of spatial alternatives

$$= \sum \sum \sum \exp\left(V_{r'} + V_{h'} + V_{a'} + V_{rh'} + V_{ra'} + V_{ha'} + V_{rha'}\right),$$

as defined in Model B below.

FIGURE 1

The Proposed Structured Logit Model System



X_s are factors in mobility choice (e.g. household income, number of children, age of head, and marital status, plus such attributes of the current location as crime, demographic characteristics, and travel accessibility).

B. Residential Location, Housing, and Auto Ownership Model

$$\mathrm{Prob}(r,h,a|s=\mathrm{move}) = \frac{\exp\,(V_r + V_h + V_a + V_{rh} + V_{ra} + V_{ha} + V_{rha})}{\sum_R \sum_H \sum_A \exp(V_{r'} + V_{h'} + V_{a'} + V_{rh'} + V_{ra'} + V_{ha'} + V_{rha'})}$$

where:

$V_r = \beta_r X_r$ = a function of factors that differ among residential locations (e.g. crime, density, land use, population characteristics, school quality, and local services)

$V_h = \beta_h X_h$ = a function of factors in housing type choice given housing type (e.g. number of children, income)

$V_a = \beta_a X_a$ = a function of factors in auto ownership decision (e.g. income, number of drivers)

$V_{rh} = \beta_{rh} X_{rh}$ = a function of factors that differ among locations and housing types (e.g. unit housing costs)

$V_{ra} = \beta_2 LS(C) + \beta_3 LS(D)$,

and $LS(C)$ = generalized accessibility to workplace = $\sum_w \sum_m \exp(V_{w'} + V_{m'} + V_{wm'})$, as defined in Model C below;

$LS(D)$ = vector of generalized accessibility measures for types of non-work travel,

$= \sum_F \sum_D \sum_M \exp(V_{d'} + V_{m'} + V_{dm'})$, as defined in Model D below.

$V_{ha} = \beta_{ha} X_{ha}$ = a function of interaction factors in housing type and auto ownership decisions

$V_{rha} = \beta_{rha} X_{rha}$ = a function of interaction factors in location, housing type and auto ownership decisions

C. Employment Location and Mode to Work Model

$$\mathrm{Prob}(m,w|r,a) = \frac{\exp(V_w + V_m + V_{wm})}{\sum_w \sum_m \exp(V_{w'} + V_{m'} + V_{wm'})}$$

where:

$V_w = \beta_w X_w$ = a function of factors that differ among workplace locations (e.g. employment opportunities)

$V_m = \beta_m X_m$ = a function of factors in mode choice (e.g. auto ownership, income)

$V_{wm} = \beta_{wm} X_{wm}$ = a function of factors that differ among workplace locations and modes (e.g. travel time and cost for home to work travel)

D. Model of Travel Choices for Home-Based Non-Work Trips

For each trip purpose category, compute:

$$\text{Prob}(f,m,d|r,a) = \frac{\exp(V_d + V_m + V_{dm})}{\sum_F \sum_D \sum_M (V_{d'} + V_{m'} + V_{dm'})}$$

where:

$V_d = \beta_d X_d$ = a function of factors that differ among destinations

$V_m = \beta_m X_m$ = a function of factors in mode choice (e.g. income, auto ownership)

$V_{dm} = \beta_{dm} X_{dm}$ = a function of factors that differ among destinations and modes (e.g. travel time and cost)

6.2 Data Requirements for Model Estimation and Validation

A. Objectives

The appropriate data for estimating and validating the proposed behavioral model is determined by three key concerns:

1. The analysis system should be applicable to different geographic areas.

2. The analysis system should be oriented toward long-range time horizons, and sensitive to dynamic shifts in behavioral relationships over time.

3. It should be possible to test the temporal reliability of the analysis system with available data.

The need for a <u>geographically generalizable model</u> approach is an important issue. A basic premise of this study design is that the resulting analysis approach will be applicable for the evaluation of a broad set of transportation-spatial form interactions for national policy analysis. At the same time, it must be recognized that the interactions with which this analysis is concerned occur fundamentally on the intra-urban level.

Many previous studies have achieved generalizable conclusions about intra-urban location behavior through the assumption of a hypothetical city. The hypothetical city is often defined to be circular, monocentric, and with no geographic features to constrain development patterns. The required simplifying assumptions have been a major cause of criticism of various theoretical and applied land use models. That approach is specifically rejected for this study, in favor of a more realistic approach based on real world data for real cities. Results are then generalized through the application of the model approach to a small number of representative urban areas, chosen to represent a range of size, density and

regional location characteristics. The initial calibration and testing of the model framework would be performed for one urban area.

The need for a model sensitive to long-range dynamic change suggests the importance of collecting data on household location behavior and a wide variety of transportation and non-transportation locational attributes. In this way, there is increased probability that the model will adequately control for intervening factors responsible for long-term dynamic shifts in observed relationships. At the same time, concern for the long-term temporal reliability of the analyis system suggests the importance of time series validation. This requires the existence of comparable data for the same study area for at least two points in time. Behavioral relationships estimated fom observed behavior in the first period may be validated against observed behavior in the second period.

B. Alternative Data Sources

There are a number of national surveys containing data on household demographic and employment characteristics, residential mobility behavior and housing choices. These include:

- o HUD Annual Housing Survey
- o University of Michigan
- o Washington Center for Metropolitan Studies Survey
- o US Census of Housing and Population, Public Use Sample Types

The first two of these surveys have the advantage that they are both longitudinally-linked data bases, and can provide data about demographic transition probabilities and changes over time in other housing and employment attributes. All of these surveys (except the Census), however, have the shortcomings that data on residential location and employment location are typically limited to central city vs. suburb (and rural)

information. This geographic scale is often insufficient to match locations to levels of taxes, housing costs, and local government services. Equally important is the fact that all of these surveys (including the Census) have little specific data on attributes of the journey to work, particularly the employment location of each household.

Local household surveys, typically collected for transportation planning purposes, overcome most of the above data problems. Many of them contain data on the socioeconomic characteristics of the households, a classification of the housing unit type, and data on prior residential mobility and location, as well as complete travel characteristics including home, work and shopping locations. It is typically possible to map their zonal systems to zonal land use and census tract data, as well as supplementary data on tax rates, level of public services, crime rates, etc. This type of data source thus best satisfies the data needs for a complete analysis of transportation versus non-transportation tradeoffs in household location decision-making.

Origin-destination surveys, together with household data and land use data sources, are available for a limited number of major metropolitan areas, such as:

Baltimore, 1977	Minneapolis-St. Paul, 1970
Atlanta, 1970	Seattle, 1970
Phoenix, 1976	Denver, 1971

Another major criterion for the selection of an appropriate data base is the ability to perform an analysis of the temporal stability and validity of the forecasting models. For example, the Minneapolis-St. Paul area, as an initial case study city, has several key advantages:

1. The 1970 household survey year coincides with the year for census data of population and neighborhood characteristics, thus facilitating integration of these data sources.

2. Forecasts based on the 1970 data may be later validated and tested against observed 1980 data on residential location patterns and travel behavior. This is facilitated by new travel data to be collected for 1980 by the Metropolitan Council, together with the eventual availability of 1980 census data.

3. The 1970-1980 time interval is sufficiently long to potentially reflect some major changes in residential location and transportation demand patterns in the intervening period. This will offer the possibility of testing the temporal validity of the behavioral model initially based on mobility and location changes collected from the 1970 period survey.

4. The 1970 Minneapolis-St. Paul survey has already been matched with land use and other supplementary data for a preliminary micro-level analysis of changes in residential mobility, housing, location and auto ownership patterns (Weisbrod, 1978).

5. The Twin Cities area is of particular policy interest as a classic example of a multi-centric urban area.

It must be stressed again that the initial analysis of data for a single urban area is intended as a test of the validity of the analysis approach for a prototype application. The eventual design is to develop a policy-sensitive model of long range change which can be applied for a number of representative case study metropolitan areas. A classificaton of different types of urban areas for the selection of case study cities is presented in Cambridge Systematics (1979).

C. Data Needs for the Model

Since the proposed behavioral model is oriented towards a broad set of transportation and non-transportation tradeoffs, it is necessary to assemble locational data from a variety of data sources. In general terms, the types of data needed are:

1. a survey of household choices concerning residential mobility, housing type, residential location, employment location, travel origins and destinations, mode choice, and auto ownership level.

2. land use data on housing units, business locations, development densities, parks and vacant land by zone within the metropolitan area.

3. census tract data on housing unit attributes and socioeconomic characteristics of neighborhoods within the metropolitan area.

4. supplementary data on the tax rates, level of public services, crime rates and education attributes of various locations within the metropolitan area, as available.

5. transportation network data in the form of travel time and costs for auto travel and public transit between all combinations of locations within the metropolitan area.

Potential variables for the proposed model are listed in Table 2.

TABLE 2

Potential Data for the Model

Residential Mobility Factors
- annual move/stay behavior
- household income
- household demographics (age, composition, children)
- Attractiveness of locational alternatives (a function of residential location factors, see below)
- Current location: crime, socioeconomic class, travel accessibility

Residential Location Factors (attributes of locations)
- travel accessibility to work (a function of travel time, cost, and mode choice probabilities, as well as employment location factors)
- travel accessibility to shopping, recreation (a function of travel time, cost and mode choice probabilities together with data on commerical land use locations)
- moving distance from last residential location
- neighborhood density, housing types
- proximity to industrial land and parks
- current age and income characteristics of neighborhoods
- current housing costs, housing unit sizes, housing opportunities per zone
- household income and demographics (age, composition, children)
- employment locations, occupations of household members
- current tax rates, level of public services, school teacher/pupil rates

Auto Ownership and Travel-Related Factors
- household composition-size, number of worers, number of licensed drivers
- household income
- transportation network characteristics (time and cost) for auto and public transit
- residential and employment locations (for the household)

Employment Location Factors
- occupation, industry type
- land use--commercial, industrial and service employment by zone within the metropolitan area
- transportation origin-destination characteristics (time, cost) for auto and public transit

<u>External</u>

- regional population change (in-migration, out-migration, demographic pattern shifts)
- regional employment change by industry type
- transportation network changes
- zoning, land use planning changes
- fuel availability and costs
- vacant land for residential and commercial development
- lifestyle factors--long run changes in labor force participation rates, household incomes, leisure time, etc.

6.3 Proposed Scenarios to be Tested

A number of alternative scenarios will be developed as part of the proposed study, to account for changes in exogenous conditions which may influence travel behavior and housing choice over the next 30 years. The role of potential scenairos in the forecasting framework is discussed in Chapter 4. The specific scenarios which have been selected for inclusion in the study are identified below.

The scenarios are organized into "packages", each of which includes a set of variable forecasts. One scenario, intended to serve as a "base case," is composed of a set of projections which conform closely to prevailing trends. Three other scenarios are also proposed for inclusion in the study. The values of at least two variables included in each of these scenarios differ significantly from those in the base case. The four proposed scenarios are defined below in terms of the variables included in each, and the data sources or estimating procedures which will be used to derive projections for the year 2010.

I. Base Case Scenario

The base case scenario is defined in terms of the following variables.

A. Demographics

1. Household Size
2. Age Composition of Household
3. Number of Households

In the base case scenario, a sample of households will be constructed which reflects rates of household formation that are consistent with current trends. The Census has estimated five series of household and family unit

projections through 1995. The demographic characteristics of the base case sample will be generated through a series of Monte Carlo transitions, the probabilities of which are consistent with the Census series that most closely corresponds to current rates of household formation. The proposed method of deriving the scenario sample will simulate proposed changes (e.g., death, divorce or marriage) in household characteristics over successive time periods (of five years duration) from a pre-specified probability distribution. At the end of each time period, each household will have undergone a complete set of demographic changes which will alter its significant characteristics. In the probabilistic sense, this sample of households each period will be used to represent the complete population. In summary, a sample of households for the base year 1980 will be simulated over the next 30 years, and in each year the sample will age and undergo various demographic transitions on a stochastic basis. This approach is directly analogous to one adopted in DYNASIM microsimulation model (see Orcutt, et al., 1976). The output of this process will be a longitudinal sample of households, where each household (except those that dissolve or are created in the simulated period) is observed at 5 year intervals for 30 years.

B. Household Economic Characteristics

1. Personal Income

2. Labor Force Participation Rates

As in the case of demographis, household economic characteristics will be simulated via Monte Carlo transitions. Transitional probabilities representing extrapolations of current trends will be based on BEA Area Economic Projections through 1990 and OBERS projections through 2020.

C. Energy Prices

1. Prices of Gasoline, Other Fuels used in Transportation

2. Prices of Fuels Used for Space Heating

As noted previously, there is a high degree of uncertainty associated with the projections of energy prices due to the range and complexity of factors which determine energy supply and demand. Until this year, projections of future gasoline price increases tended to be close to 3 percent per year. However, over the last two years, prices have increased at a rate of nearly 50 percent annually. In the base case, it will be assumed that fuel prices continue to rise at a rate significantly greater than 3 percent over the next 3-5 years, until prices are high enough to support the producton of petroleum from alternative sources, e.g., shale deposits. At this point, it is assumed that annual price increases will return to the pre-1978 average of 3 percent.[1]

D. Housing Prices

In the base case, it will be assumed that price increases average 2-3 percent over the rate of inflation through the 1980s, as the presence of large numbers of young adults in the housing market results in a steady increase in housing demand, and resource shortages add to the cost of supply. It is assumed that demand pressure will abate somewhat after 1990, and that housing prices will stabilize in constant dollar terms.

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[1]These proposed rates are tentative. The final scenario may be modified to reflect more recent industry, government, or independent projections.

E. Technological Development

1. Substitution of Communications for Transportation

2. Electric Cars

3. Increased Fuel Economy of Conventional Vehicles

It is assumed in the base case that there will be no significant breakthrough in electric vehicle battery technology, and that EVs will represent a relatively small percentage of the vehicle fleet (less than 10 percent). It is further assumed that the degree of substitution of communication for transportation will be insignificant. The fuel economy of conventional vehicles, i.e., those utilizing internal combustion engines, will be maximized.

II. High Travel and Housing Cost Scenario

This scenario is designed to represent a possible future where demand for energy and housing increases at a greater rate, while there are no major breakthroughs in lowering transportation fuel consumption rates, energy supply costs or unit housing construction costs. This scenario will be presented in the form of one "core" scenario and three variations. The core scenario will incorporate the following assumptions:

1. Average household size will exceed that in the base case by 20 percent due to increased fertility rates.

2. Energy price increases will exceed those in the base case, as current trends continue and prices are not stabilized by an introduction of shale oil extraction.

3. Housing costs will exceed those in the base case, due to continued materials and resource shortages.

Variations:

a. In the first of three variations of this scenario, the population growth rate of the area studied will exceed that of the nation as a whole, due to in-migration.

b. The second variation will incorporate a lower rate of growth in personal income than the base case.

c. The third variation will incorporate a higher rate of growth in personal income than the base case.

A. Demographics

1. Household size: average increase 20 percent over base case

2. Age composition of households: lower due to more children than in base case

3. Number of households: no change from base case

The demographic characteristics incorporated into this scenario will differ from those in the base case only in relation to the assumed fertility rate, which will exceed that of the base case. The increase in the fertility rate will be represented by altering the transition probabilities applied in generating the study sample. The probabilities will be based on Census "high fertility" scenario projections.

B. Household Economic Characteristics

1. Personal Income: no change from base case in "core" scenario; variations a and b reflect lower and higher growth rates than the base case.

2. Labor Participation Rates: no change from base case.

C. Energy Prices

Final projections will be based on the most recent available data.

Tentative proposals are as follows:

1. Price of Gasoline: increase at twice the rate projected in the base case.

2. Price of Fuels Used for Space Heating: increase at twice the rate projected in the base case.

D. Housing Prices

Housing prices will increase at a rate which exceeds the overall pace of inflation by 5-6 percent throughout the 1980s, and 3 percent thereafter, due primarily to increased costs of construction materials. These and other projections of housing and energy costs may be adjusted to reflect more current data.

E. Technological Development: no change from base case.

III. Rapid Technological Development Scenario

This scenario will reflect significant development of electric vehicle and communications technology. In the core scenario, only technological factors will vary from the base case. In a variation of this scenario, the effects of energy price increases in excess of those represented in the base case will be considered in combination with the effects of rapid technological advancement.

Variables:

A. Demographic Factors: no change from base case

B. Household Economic Conditions: no change from base case

C. Energy Prices: In a variation of the core scenario, energy prices will be assumed to increase at twice the rate represented in the base case.

D. Housing Prices: no change from base case.

E. Technological Development

1. Substitution of Communications for Transportation--This scenario will be designed to represent an upper bound for the substitution of communications for work-trip travel. Occupations consisting predominantly

of communicative, transactional, and conceptual functions are the most logical candidates for work-trip substitution. Estimate of the number of employees in these occupational categories within the metropolitan area chosen for study will be developed, using BEA and OBERS projections of area employment by industry. This estimate will represent the maximum number of daily work trips which could be eliminated by communications technology.

2. Electric Vehicle--It will be assumed in this scenario that there will be significant advances in electric vehicle battery technology which extend the range of electric vehicles. The electric vehicle will become an attractive option for commuter and other relatively short distance trips, particularly among two-car family households. The effects of electric vehicle use will be represented as reduced fuel costs for travel by this mode.[1]

3. Increased Fuel Economy of Conventional Vehicles: no change from base case.

IV. High Housing Cost Scenario

This scenario will incorporate a more rapid rate of increase in housing prices than that in the base case scenario. In conjunction with higher housing prices, it is assumed that labor force participation rates will increase to provide additional household income for payment of housing costs. In a variation of this scenario, it will be assumed that there is significant substitution of communications for work-trip travel.

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[1]It will be assumed that the use of electric vehicles does not significantly affect the price of gasoline or other fuels.

A. Demographics: no change from base case

B. Household Economic Conditions: increased labor force participation

C. Energy Prices: no change from base case

D. Housing Prices: constant dollar housing prices will increase by 5-6 percent throughout the 1980s, and 3 percent thereafter until 2010, due to increased costs of materials used in home construction.

6.4 Development and Testing of the Proposed Analysis System

The proposed study design involves seven major phases:

1. Collection of data, as outlined in Section 6.2, for one case study metropolitan area (1970 data)

2. Estimation of econometric model coefficients for the case study area, for the model framework outlined in Section 6.1.

3. Forecasting of changes in residential development patterns for the case study area for the 1980 time period, with appropriate adjustments for changes in exogenous factors.

4. Model validation and testing by comparing the model forecasts for 1980 with actual 1980 residential location and resulting travel patterns. On this basis, omitted factors and other possible problems with the model will be identified.

5. Model re-estimation and modification as a result of phase 4 results.

6. Forecasts of long-run (30 year) changes in residential location patterns and their transportation implications, for each of the alternative future scenarios described in Section 6.3.

7. An evaluation of the value of the prototype model application for further long-term forecasting analysis.

6.5. Summary of Applications and Benefits of the Proposed Analysis

The study of transportation and housing choice interactions outlined in this report is designed to serve as a basis for long-term policy analysis and planning. The key factors influencing the development of the study approach are as follows:

1. The interaction of transportation and residential locations is an area of key current and future policy interest. Transportation and housing both have a central role in determining individual lifestyles. These areas are also the subject of special interest at the present time, since it appears that future societal changes may have a profound impact on urban spatial form and the market for transportation.

2. Since travel and residential location decisions are so closely interrelated, it is impossible to forecast long-term changes in one area in isolation from the other.

The study will provide insights into the nature and extent of potential long-term change in the areas of transportation and housing. In addition, the methodology developed as part of the study will have applications in a broad range of future policy analysis and planning efforts. The study is proposed at a time when current and anticipated social and economic forces may induce significant change in patterns of travel behavior and housing choice. In particular, such unknowns as future energy prices, transportation technology, housing costs, and demographic characteristics may fundmentally alter the future relationship between travel and housing choice decisions. Existing methods of analysis which do not specifically account for potential changes of this nature lack the capability to address questions which are significant from the perspective of long-term planning.

The characteristics of transportation and housing patterns in the future will be influenced by current infrastructure investments and policy decisions. The approach developed in the proposed study can be used to evaluate the future impacts of a broad range of alternative policies, including the following:

- o highway and transit investments
- o funding of transportation technology development
- o aid to cities, including law enforcement and education grants
- o community and neighborhood development grants
- o housing subsidy programs

The proposed method for analyzing transportation/housing choice interactions is designed to provide a realistic representation of individuals' responses to the above categories of policies over a long-term period. For example, the effectiveness of housing subsidies can be represented in the modelling framework as a reduction in housing costs for affected households; the effect of the policy in relation to other factors influencing housing choice (e.g., accessibility, crime, socioeconomic factors) can then be explicitly determined through execution of the transportation/residential location choice model. The information provided by the forecasting procedure can thus serve as a basis for formulating policy and allocating funding among competing programs.

The methodology developed through the study will be used for analysis of data at the metropolitan-area level. While the methodology may have applications in local planning efforts, the current approach is

primarily oriented towards national level policy analysis. It is intended that the results of the forecasting procedure applied at the metropolitan area level will be used to draw inferences upon which major investment policies can be based. The immediate study will focus on only one metropolitan area. While it is believed that the study results will yield revealing insights into the dynamics of exogenous conditions, travel behavior, and housing choice, the proposed project is also of immediate value as a model for future analyses to be conducted in additional cities. The focus on individual metropolitan areas corresponds to the scale at which transportation and housing decisions occur. It is anticipated that for purposes of national policy analysis, studies similar in nature to the one proposed will eventually be conducted for a limited sample of cities which are representative of conditions throughout the US.

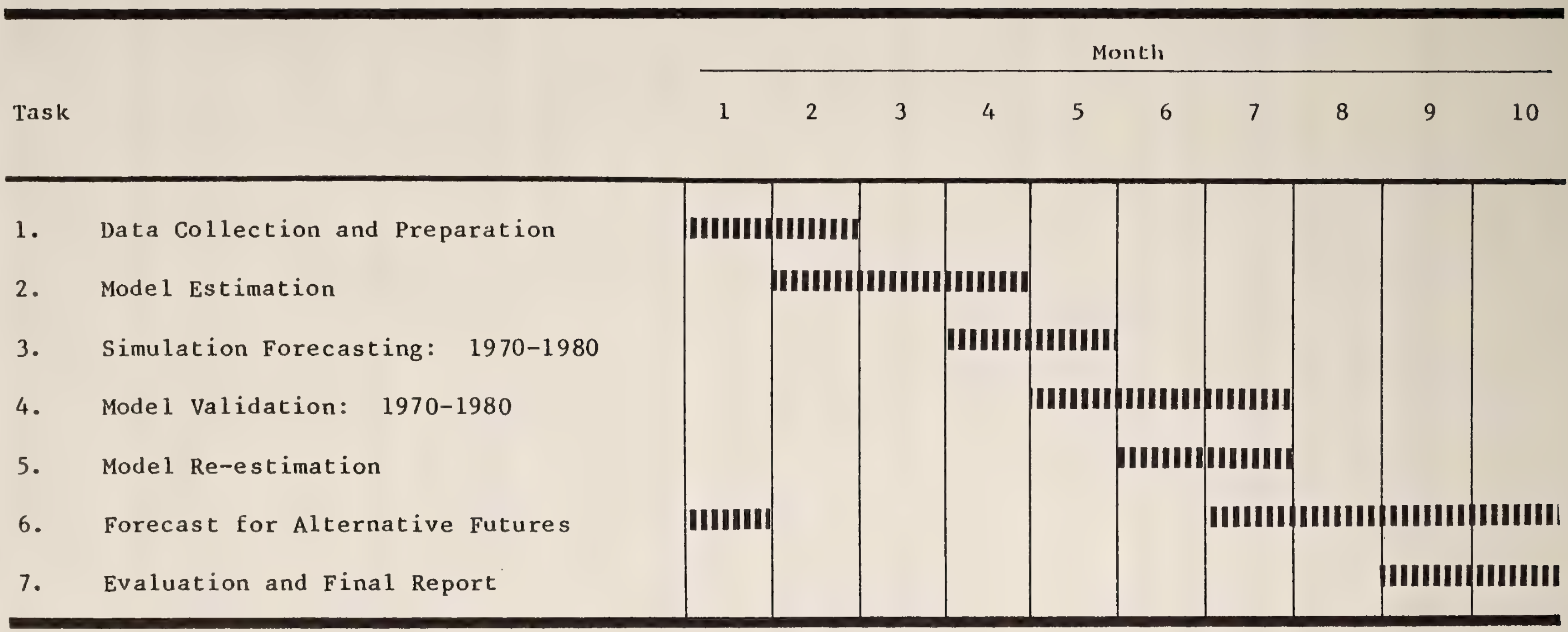
While the proposed analytical approach is intended primarily as a tool for applied policy analysis, the study does also contribute to the development of urban spatial research techniques. The study methodology is explicitly designed as a component of a broader framework of spatial analysis tools. As noted previously, housing location decisions represent only a single element of a larger set of factors contributing to urban spatial form. The broader framework of spatial phenomena includes the location decisions of firms, government agencies, and other institutions. The segment of that framework developed through the proposed study will serve as a single module which can be integrated with other components to construct a unified methodology for the analysis of spatial phenomena.

The resources required for application of the approach include metropolitan-area level data on travel behavior, housing, population, income, employment, and other factors to be used in the calibration of models and forecasting. Since it is assumed that the approach will initially be applied primarily by policy-makers and analysts at the national level, these users will generally need to enlist the aid of state, local or regional agencies in collecting transportation, land use, tax, education and crime data. The execution of the analysis will require computer capabilities and eventual guidelines for applying the models to other policy analysis scenarios.

The advantage of the proposed approach is that it is sensitive to the full range of variables which influence travel and residential choice behavior, and is therefore more effective as a tool for policy analysis than more aggregate land use analysis techniques. Unlike aggregate techniques for forecasting spatial land use patterns, the proposed method explicitly represents the decision process of individual decision-makers in a dynamic framework. This method of analysis can more readily incorporate the full set of socioeconomic factors which influence travel behavior and housing choice. In comparison to alternative methods based on large-scale models of urban land use, the "micro-level" approach proposed is more adaptable and less complex, yielding major savings in computer time and data storage demands. The forecasting approach is well-suited to the analysis of a wide variety of exogenous conditions. The inclusion of detailed scenarios as a major element of the analysis will establish the bound of exogenous variables likely to influence

long-term transportation behavior and residential choice. This will increase the utility of the proposed approach as an analysis tool, since policy impacts will be analyzed in the context of realistic future social and economic conditions.

Proposed Project Schedule



TECHNICAL APPENDIX A

Extensions of Aggregate Modelling Approach[1]

One approach to modelling locational change in residential and employment mobility is the use of interzonal "transition probability matrices." An underlying problem with such an aggregate-level approach is that merely tabulating existing data and creating a transition matrix requires the estimation of too many independent parameters to be estimated from a data sample of any reasonable size.[2]

One way to reduce the number of parameters is to relate the entries in the matrix to observable independent variables. This can be done in a virtually limitless number of ways, two of which will be explored below. The first, somewhat crude approach is to maintain the original concept of transition matrices, but to structure them so that there are fewer independent cells to be estimated. The second approach departs somewhat from the transition matrix concept by building an explicit parametric model of the interzonal transition probabilities.

In the first approach, we begin by expressing every transition probability as the product of the probability of changing workplace and/or residence, and the choice of where to relocate. This partitioning of the choice process is consistent with much of the theoretical and empirical evidence discussed in the literature.

Second, we represent choices among discrete attribute combinations rather than physical workplace/residence pairs, thereby reducing the number

[1]Portions of this appendix were originally developed in a paper by Lerman and Weisbrod (1979) for The Netherlands Ministry of Transport.

[2]Each cell in the probability matrix can be viewed as a parameter to be estimated, and if the matrices are KxK, there are Kx(K-1) independent parameters, since each row should sum to one.

number of transition probabilities to a more manageable number (assuming that the number of attributes and the number of discrete levels are small).

As an example of the above approach, suppose the only attribute that was assumed to affect relocation was life cycle (as measured by age and whether or not there were children in the household. The first transition matrix (i.e., the one for relocation) might be structured as follows:

LIFE CYCLE	PROBABILITIES Change Residence Only	Change Workplace Only	Change Both	Change Neither	$\sum$
Under 40 yrs old w/o children					1.0
Under 40 yrs old w/ children					1.0
Over 40 yrs old w/o children					1.0
Over 40 yrs old w/ children					1.0

Obviously, this could easily be expanded to include more socioeconomic variables <u>as well as attributes of the current location</u> such as residential density or employment mix at the workplace.

The second matrix would be a tabulation for movers (either workplace, residence, or both) which also represented each alternative choice as a discrete bundle of attributes. For example, suppose a residence/workplace combination was described by attributes such as travel time to work by the fastest mode, residential density (at residence), and employment density (at workplace). The relevant transition matrix would be a three-way contingency table, with discrete levels corresponding to contiguous and non-overlapping ranges of each of the three attributes.

Each cell of the probability matrix would be denoted as P_{ijk}, where the subscripts i, j, and k denoted the discrete categories of the first, second, and third variables respectively. Each entry would be the probability that the bundle is selected. If the individual was changing only residence, then only those cells with residence attributes identical to their current choice would be considered; all the relevant probabilities for that portion of the matrix would be normalized to sum to one. Individuals who were only changing workplace would be similarly constrained.

This method can readily be extended to incorporate the socioeconomic characteristics of the individual simply by having different matrices for each relevant socioeconomic group.

The final step in applying this approach would be to divide the expected number of people selecting an attribute bundle among the residence and workplace combinations which possess those attributes. The simplest way to accomplish this last step would be to consider the likelihood of any pair of candidate residence and workplace zones being chosen as proportional to a measure of the relative "size" of the zones, where size is measured by the stock of housing (in the case of residence) and employment (in the case of workplace).

The above approach has both merits and drawbacks. The positive aspects of the approach are as follows:

1. As long as the number of attribute categories is small, the number of cells or probabilities to be estimated can be kept to a reasonable number. This should allow for reliable parameter estimates.

2. In a behavioral sense, individuals are more reasonably represented as choosing among attribute bundles than among specific sites.

3. If the attributes are chosen in a way that reflects the influence of public policy, then the model's predictions will begin (albeit in a crude way) to reflect the impacts of those policies on the spatial distribution of residences and workplaces.

The drawbacks of this approach are:

1. Many of the attributes of interest are inherently continuous, while the above approach requires discrete attribute categories. Thus, there is a loss of information associated with categorizing various attributes. Segal (1977) argues, from evidence presented by Goldberger (1977), however, that the information loss is relatively small as long as the number of categories is fairly large (i.e. 5-10).

2. While the approach does add policy sensitivity to the model, it is still relatively ad hoc; no explicit behavioral relationships are assumed in representing people's preferences. For example, increases in some attributes (such as transportation cost and time) should logically be associated with monotonically decreasing choice probabilities. In the above approach, this may or may not occur since there are no constraints on the probability estimates. This shortcoming may be particularly troublesome when relatively small samples are used, since it may be impossible to obtain reliable estimates of the probabilities for each level of travel time and cost.

3. The practical limitations of this approach in terms of the limited number of independent variables which can be used may introduce significant specification error into the model structure. This could lead to extremely misguided policy impact forecasts.

Parameterizing Cell Probabilities

The most critical problem with the transition matrices discussed in the previous section is that they fail to utilize any behavioral theory of decision-making in predicting cell probabilities. In a sense, they fail to utilize the analyst's understanding of the problem in forecasting various transition probabilities.

Consider a single row of the original transition matrix discussed in in Section 1 and normalize each cell value by the row total so that any entry can be fiewed as the probability of a randomly drawn individual

residing at A and working at B at time t_0 will be residing at C and working at D at time $t_0 + \Delta_t$. As before, let us use i to denote the row, and j to denote the column. P_{ij} will be the transition probability (equal to $V_{ij}/\sum_j V_{ij}$) in the notation of Section 1.

One possible way to make the forecast P_{ij}'s for any period more policy sensitive is to forecast them in an explicit model. For example, one might consider a model of the form

$$P_{ij} = \frac{e^{f(x_i,x_j,x_{ij})}}{\sum_{j'} e^{f(x_i,\, x_{j'},x_{ij'})}}$$

where

x_i is a vector of variables describing i such as average income, age, occupational mix, average stay, housing mix at residence, industry mix at workplace, etc.

x_j is a vector of variable describing j such as those used in x_i

x_{ij} is a vector of variables describing interactions between i and j such as travel time to work

$f(x_i,x_j,x_{ij})$ is a function.

This model is easily estimated if $f(x_i,x_j,x_{ij})$ is linear in its parameters. Let $Z_{ij} = g(x_i,x_j,x_{ij})$ be a vector of independent variables, where g has no parameters to be estimated. If $f(x_i,x_j,x_{ij}) = \beta Z_{ij}$, then the equation above can be re-expressed as follows:

$$\ln \frac{P_{ij}}{P_{ik}} = \beta(Z_{ij} - Z_{ik})$$

This equation can be estimated by least squares as long as none of the $P_{ij} = 0$. The choice of the transition matrix probability to act as a base (P_{ik}) is wholly arbitrary, and Theil (1969) develops a procedure in which the estimated parameters are unaffected by the choice.

The theoretical advantage of this approach over the method discussed in Section 3.a is that it uses the information available more fully. Monotonic relationships between the choice probabilities and particular Z_{ij}'s are imposed by the choice of functional form and continuous variables are not discretized.

The practical advantage is that the number of parameters in the proposed model will be relatively small, and the number of potential independent variables can be expanded. Moreover, forecasting with the model is straightforward, since the full transition matrix can be readily forecast using the model.

Note that this approach represents a "midway" point between the macro level transition models and a fully disaggregate model. It uses only the aggregate level data, but imposes a functional form identical to multinomial logit. It is important to stress that the only thing gained in this approach over using multinomial logit with disaggregate data is that it permits use of aggregate data and computationally less costly estimation software. The added statistical efficiency in the parameter estimates that use of disaggregate data provides is lost, and error due to aggregating across individuals in each cell of the matrix is introduced. The decision as to whether aggregate estimation of choice probabilities is worthwhile depends on the weights placed on these relative advantages.

TECHNICAL APPENDIX B

Methods of Aggregate Forecasting with Disaggregate Models[1]

This appendix summarizes the significant theoretical and methodological issues in making aggregate forecasts with disaggregate models. The review will include a rather abstract theoretical treatment of various approaches along with a summary of the more relevant, practical implications of various approaches. It will be organized into two major sections. First, a basic notational apparatus will be set up and the basic problem will be formalized. The following section will describe four distinct (though not necessarily mutually exclusive) approaches to making aggregate forecasts with disaggregate models. Each approach will be presented in a separate subsection and will include both a theoretical development of the approach and some practical comments about its usefulness in various contexts.

For the sake of brevity, both the theoretical and practical aspects have been kept relatively terse. Further details can be found in references cited in Chapter 5.

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[1] Portions of this appendix were originally developed in a memorandum by Lerman to the Electric Power Research Institute.

A.1. Aggregating Disaggregate Models

a. Theoretical Development

Let us begin by defining T as the population of interest and assume that T is large enough so that for all practical purposes it can be treated as infinite. Suppose the behavior of each individual in T can be described as a process of choosing one option from a set of mutually exclusive and collectively exhaustive discrete alternatives. Define that set as C. Let the model of individual behavior be defined as $P(i|z)$ where z is a vector of choice-relevant characteristics (including attributes of alternatives and of decision-makers), and i is some member of C, and $P(i|z)$ is the probability that alternative i is selected from set C given attributes z. Let Z be the space of possible vectors z.

Suppose that the attributes z are distributed in the population T with generalized density $p(z)$. The problem of making aggregate forecasts using disaggregate models can then be represented as one of finding the expected aggregate share of the population choosing each alternative i in C. Let $Q(i)$ be the expected aggregate share of T choosing $i \varepsilon C$.* Mathematically,

$$Q(i) = \int_Z P(i|z)p(z)dz$$

* Another interpretation of $Q(i)$ is the probability that an individual from T drawn at random will choose alternative i.

This integral requires complete knowledge of the distribution $p(z)$ as well as a computationally practical method for solving the integral; in general, neither is available. However, a variety of techniques to either estimate or approximate $Q(i)$ have been developed.

In some very simple cases, the integral expression for $Q(i)$ can be solved quite readily. For example, if $P(i|z)$ is linear, then $Q(i) = P(i|\bar{z})$, where $\bar{z}$ is the mean of z. Alternatively, if $p(z)$ is degenerate in the sense that the entire population has identical attributes $\tilde{z}$, , then $Q(i) = P(i|\hat{z})$. More realistically, however, $P(i|z)$ is non-linear and $p(z)$ is an often complicated multivariate distribution involving both continuous and discrete variables. In such cases, it is often infeasible to evaluate $Q(i)$ directly and some simplifications are required.*

b. <u>Some Practical Comments</u>

As a practical matter, the model $P(i|z)$ is typically one of a very small class of discrete choice models. In most applications, $P(i|z)$ arises from a model of random utilities. The most widely used such model is conditional logit, i.e.

$$P(i|z) = \frac{e^{\theta z_{it}}}{\sum_{j \varepsilon C} e^{\theta z_{jt}}}$$

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* It is also the case that $P(i|z)$ is usually neither strictly convex nor concave, so it is often impossible to tell whether simple approximations such as $Q(i) = P(i\,|\,\bar{z})$ are upward or downward biased.

where:

z_{it} is the portion of the complete vector of attributes z that is relevant to alternative $i \in C$ and decision-maker $t \in T$; and

θ is a vector of parameters.

The other model form that will be considered is probit, in which the random utilities are assumed to be multivariate normal with known variance-covariance matrix.

Knowledge about p(z) can come from a variety of sources. In some cases, information about p(z) may result from exogenously set factors. For example, prices may be set by a regulatory agency, and their distribution conditional on some of the other attributes may be known. Other knowledge about p(z) may include certain moments of the distribution developed from published sources such as Census data. In some instances, the marginal distribution of some variables in Z may also be published. Finally, p(z) may be assumed to belong to a particular class of distributions (such as the multivariate normal), so that knowledge of a limited number of moments implies a complete description of the distribution.

A.2. Methods of Aggregate Forecasting

There are four basic approaches that have been used to make aggregate forecasts. These are:

a. use of statistical differentials;

b. approximation of p(z) as a contingency table;

c. approximation of p(z) with an analytic form for which the integral defining Q(i) is tractable; and

d. sample enumeration

Each of these is considered below.

a. Use of Statistical Differentials

i) Theory

Begin by expanding $P(i|z)$ about $\bar{z}$, the mean of $p(z)$. Assuming all the derivatives of $P(i|z)$ exist around $\bar{z}$, this expansion yields

$$P(i|z) = P(i|\bar{z}) + \left.\frac{\partial P(i|z)}{\partial z'}\right|_{z=\bar{z}} (z-\bar{z})$$

$$+ 1/2(z-\bar{z})' \left.\frac{\partial^2 P(i|z)}{\partial z\, \partial z'}\right|_{z=\bar{z}} (z-\bar{z}) + R(z)$$

where $R(z)$ is a remainder term.

If we now integrate the expanded $P(i|z)$ to find $Q(i)$, we get

$$Q(i) = P(i|\bar{z}) + 1/2 \sum_j \sum_k \left.\frac{\partial^2 P(i|z)}{\partial z_j\, \partial z_k}\right|_{z=\bar{z}} \mathrm{Cov}(z_j, z_k) + S(z)$$

where $S(z)$ is another remainder term involving a sum of integrals of higher order derivatives of $P(i|z)$ multiplied by the corresponding central moments of $p(z)$.

If we ignore $S(z)$, $Q(i)$ can be approximated knowing only the mean and variance of $p(z)$.

ii) Some Practical Discussion

It is important to note that the remainder term S(z) does not have the same properties as R(z). In particular, if the higher order moments of p(z) get large, the absolute value of S(z) can actually be larger than the second order term. It is straightforward to generate reasonable situations in which approximating Q(i) as simply $P(i|\bar{z})$ is actually better than the approximation which includes the second order term (See Koppelman, 1975).*

Numerical experiments with this technique by Koppelman (1975) have generally indicated that the approach performs poorly and that it is dominated by other options. Talvitie (1976) has a further discussion of this approach as applied to multinomial logit.

b. Use of Contingency Table

i) Theory

Approximate p(z) as a probability mass function by partitioning Z into mutually exclusive and collectively exhaustive sets Z_1, Z_2,...Z_k and selecting some values $(\tilde{z}_1, \ldots \tilde{z}_k)$ as representative for the partition. Let

$$r(k) = \int_{Z_k} p(z)dz$$

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* These situations are characterized by p(z) having relatively high variance.

Using this, we can approximate Q(i) as follows:

$$Q(i) \cong \sum_{k=1}^{K} P(i|\tilde{z}_k)r(k)$$

ii) Practical Issues

As a practical matter, the sets Z_k are usually defined to be intervals on the dimensions of Z. For example, one might define three income classes, two levels of housing costs, etc. In these cases, the $\tilde{z}_k$'s are often taken as either the midpoints of the intervals or as estimates of the means of z conditional on their being in Z_k. Obviously, for some variables the uppermost range of z is unbounded, and so some estimate of the conditional mean is required.

In most applications the number of independent variables is quite large, and developing and forecasting a contingency table is often a non-trivial problem. In some cases, the underlying structure of the contingency table is simplified by making some plausible assumptions about the independence of some attributes from others. (See, for example, McFadden, et al. (1977)). For example, it is frequently (although perhaps incorrectly) assumed in transportation demand model applications that within a relatively small zone, traveller's in-vehicle time, out-of-vehicle time and out-of-pocket cost for various trips are independent of their income, auto ownership, and other socioeconomic attributes. Obviously, any particular set of simplifications must be judged in the context of the specific application at hand.

Most of the empirical evidence indicates that the use of a contingency table to approximate $p(z)$ works quite well even when K, the number of categories selected, is quite small. Two general "rules of thumb" have arisen from a number of numerical studies. First, it appears to be critical to select the Z_k's in a way that reflects different availability of alternatives. For some values of z, it is often the case that $P(i|z) = 0$. For example, suppose one is predicting mode choice and one alternative is driving alone to work. If a traveller does not have a driver's license, then this alternative is simply infeasible. The partition of Z should be set up so that this portion of the population is separated from the remainder for whom driving alone is feasible.

The second "rule" is that two factors should be considered in deciding how many intervals to use for a particular independent variable. The first factor is the amount of variation in that attribute over the population, and the second is the relative "importance" of that variable in the choice process. Intuitively, attributes with a great deal of variation should be segmented finer than those without much variation. However, those attributes which (in an intuitive sense) do not play a major role in the choice process should not be segmented finely. When attributes are entered linearly in utility functions, it is at least intuitively reasonable to consider the variation in the product of the coefficient and the attribute.

c. Approximation of p(z) with Analytic Distribution

i) Theory

Suppose p(z) is generated by a random utility maximization process and that

$$U = \beta z + \varepsilon$$

where

ε is a vector of random disturbances with mean zero; and

β is a matrix of possibly random coefficients.

In these cases, it is often possible to assume z has some known distribution and solve for Q(i) explicitly.

Let

$$z = \bar{z} + \psi$$

where $\bar{z}$ is the mean of z.

Without loss of generality, we can write for an individual

$$U^* = \beta \bar{z} + \beta \psi + \varepsilon$$

Now suppose we have some population for which we want to forecast Q(i). If the distribution of ψ in that population, $p(\psi)$, is known then we can solve for Q(i) by the following:

$$Q(i) = P_r(U_i^* \geq U_j^* \; \forall \; i,j \in C, \; i \neq j)$$

The key to this approach lies in finding some function $p(\psi)$ which in linear combination with the disturbance ε yields an analytically tractable aggregate level choice model. To date, only two such combinations

have proven both plausible and workable:

<u>Case 1</u>: ε is multivariate normal (i.e., a probit choice model with fixed coefficients) and ψ is normal;

<u>Case 2</u>: ε is independent and identically distributed as Weibull (i.e., a logit choice model) and ψ is normal.

Case 1 (originally developed for binary choice by McFadden and Reid (1975) and extended to multinomial choice by Bouthelier and Daganzo (1977)) yields an aggregate probit model. If the variance-covariance matrix of ε is Σ_ε and the variance-covariance matrix of z is Σ_z, then U* is distributed normally with mean $\beta\bar{z}$ and variance-covariance matrix $\Sigma_\varepsilon + \beta\Sigma_z\beta'$.

Case 2 (originally developed by Westin (1976)) yields a vector U* with the so-called S_B distribution with the same moments as the probit. This distribution is easily tabulated for two alternatives but little analysis has been done with larger choice sets.

<u>ii) Practical Issues</u>

Most of the experimentation with this approach has been with probit models. Tests have indicated that the normal approximation of p(z) is relatively robust except for integer independent variables such as auto ownership or labor force participation. In these cases, it is possible to first segment the population by the integer variables and assume the remaining z's are conditionally normal. Obviously, this approach carried to an extreme leads to a contingency table approximation of p(z).

Bouthelier and Daganzo have also experimented with deriving some of the moments of p(z) by using a geometric probability analysis of variously shaped zones. This is particularly relevant to travel demand forecasting since the distribution of variables such as walk time to a transit station is often critical.

It should be noted that determining Σ_z may be as complicated as developing a relatively detailed contingency table. Little work has been done in this area beyond analyzing the geometry of a zone to determine the portion of Σ_z related to transportation level of service variables.

d. Sample Enumeration Procedures

i) Theory

Consider the space defined by the Cartesian product CxZ. Suppose we partition this space into B mutually exclusive and collectively exhaustive sets, called strata, defined as $(CxZ)_1$, $(CxZ)_2$, ... $(CxZ)_B$. Define a stratified sample as one drawn by the following steps (See Manski and McFadden, 1979).

1. Select a total sample size N and sampling fractions (H_b, b=1,...B) which are the portion of the sample drawn from each stratum.

2. Draw for each stratum a total of $N_b = H_b \cdot N$ decision-makers at random from the subpopulation of T defined by $T_b = (t \varepsilon T\colon (i_t, z_t) \varepsilon (CxZ)_b)$ and observe the associated pair of choice and attributes.

Suppose we know F_b, b=1,...B, the fraction of the population in each stratum. If $\Psi(z)$ is cumulative distribution of z in the entire population, and $\Psi(z|b)$ is the cumulative distribution of z in T_b, then we know from simple probability considerations that (see Lerman and Manski (1979a))

$$\Psi(z) = \sum_{b=1}^{B} \Psi(z|b)F_b$$

Moreover, if we denote $\hat{\Psi}(z|b)$ as the observed empirical distribution of z in the sample of N_b observations, then

$$\hat{\Psi}(z) = \sum_{b=1}^{B} \hat{\Psi}(z|b)F_b$$

is a consistent estimate of the population distribution.

The result implies that any stratified sample can be used as representative of the population. Aggregate shares can be estimated consistently as

$$\tilde{Q}(i) = \sum_{b=1}^{B} \frac{F_b}{N_b} \sum_{n=1}^{N_b} P(i|z_{nb})$$

where the subscript nb denotes the n^{th} observation in stratum b.

Lerman and Manski note four things about the above procedures:

1. When $B = 1$, the sample is simply a random one and F_1 is by definition 1. In such cases this procedure is termed random sample enumeration forecasting.

2. It is assumed that the population shares F_b, $b=1,...B$ are known. Lerman and Manski discuss methods of estimating F_b from available sources.

3. This procedure does not make any assumption about the choice process or impose any restrictions on the form of p(z).

4. Different sample designs will yield different estimates of Q(i) with different statistical properties. There is currently very limited theory on what constitutes a 'good' design.

ii) Practical issues

As a practical matter, there are three cases of stratified samples which are of general interest:

1. random samples (i.e., $B = 1$ and $(C \times Z)_1 = C \times Z$.)

2. Exogenous stratified samples -- samples in which the partitioning of $C \times Z$ is done solely on attributes (i.e., $(C \times Z)_b = C \times Z_b$ for all $b = 1,...B$)

3. Choice-based samples -- samples in which the partitioning of $C \times Z$ is done solely on the choice set (i.e., $(C \times Z)_b = C_b \times Z$)

To date, only random and exogenous stratified samples have been used in sample enumeration forecasting. However, the recent increased use of choice-based samples for model estimation should also encourage their use

in forecasting.

Sample enumeration procedures tend to be easily adapted for use in systems of demand models in which each individual faces a large "decision-tree" with a great number of final branches. In such cases, it has proven useful (for computational reasons) to use Monte Carlo simulation at each branch in the tree and to probabilistically assign each individual to a specific branch. This obviously implies some loss of information in that the full set of final choice probabilities get reduced to a single, simulated outcome. However, if the original sample is relatively small and further precision on the estimate of Q(i) is needed, each observation can be replicated any number of times and used for independent drawings in the Monte Carlo experiment.

APPENDIX C

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APPENDIX D

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. A microbehavioral conceptual framework encompassing all spatial phenomena and dynamic response marginal adjustment models were introduced as concepts for analyzing residential housing and location patterns.

Methodology for Comparative Analysis of Urban Spacial Structures

DEVELOPMENT AND TESTING OF METHODOLOGY

FOR

COMPARATIVE ANALYSIS OF URBAN SPATIAL STRUCTURES

STUDY DESIGN REPORT AND MASTER PROGRAM SCHEDULE

Submitted to:

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* Section not included

I. MATHEMATICAL CHARACTERIZATION OF URBAN SPATIAL STRUCTURE: THE PROBLEM IN HISTORICAL PERSPECTIVE

A. The Gap Between Theory and Data

A rigorous method for quantifying urban spatial structure is essential for comparative analysis of alternative urban transportation-land use systems, existing or planned. Although the various social sciences have treated specific aspects of urban spatial organization, there appears to be little tendency toward convergence on any comprehensive method for empirical analysis of the dimensions of real-world urban space.

Sociological discussions of urban space, proceeding typically in the tradition of human ecology (Park, Burgess, and McKenzie, 1925; Hoyt, 1939; Harris and Ullman, 1945; Hawley, 1950; Duncan and Schnore, 1959; Theodorson, 1961), seem fundamentally correct in conceptualizing urban space as a complex territorial arrangement of differentiated population and socioeconomic activity patterns geographically structured in accordance with the spatial dimensions of social organization. However, entangled in a complexity of concepts invoked for description of social organization proper, such discussions have offered few methodological suggestions for systematic analysis of the interdependence between social organization and the order of urban space.

Economic theories of urban space (Wingo, 1961; Alonso, 1965), formulated in the fashion of the equilibrium-seeking deterministic models of space location theory (Lösch, 1954; Isard, 1956), achieve admirable quantitative treatment of primary real-estate forces at work determining overall "urban-suburban-rural" distribution of land uses in metropolitan regions. However, confronted with serious mathematical

indeterminancies arising from the locational interdependencies among differentiated households and firms, the utility of such mechanistic models for explaining the richness of real-world urban landscapes is severely limited (Koopmans and Beckmann, 1957; Tiebout, 1961; Harris, 1961).

Geographers, such as Berry (1963, 1971), have sought a theoretical basis for explanation of intra-urban commercial activity structure within the concepts and propositions of central place theory. Most of these concepts were formulated originally by Christaller to explain the hierarchical pattern of cities, towns, and villages within a region in terms of an efficient geographic spacing of economic activities of varying degrees of specialization (Ullman, 1941; Vining, 1955; Berry and Garrison, 1958).

Given the discrete clustering of non-agricultural activities into spatially separate urban centers, central place theory seems well suited as a theoretical basis for spatial analysis at the regional scale. In fact, Lösch was able to derive mathematically similar hierarchical systems of regional settlement patterns and accompanying market areas by analysis of the scale economies of various economic activities. Thus, he demonstrated that, within certain simplifying assumptions, the essential characteristics of the macro-geographic phenomena conceived by Christaller may be derived from micro-behavioral economic assumptions alone (Lösch, 1954).

However, upon entering the economic space of any single city, the spatial clustering of economic activities becomes much more complex. While scale economies and transportation costs continue to encourage dispersion of similar retail and service activities over equi-populated sub-areas of the city, other classes of competing activities often exist

side-by-side in Hotelling fashion (Hotelling, 1929). The market areas of individual retail and service activities cannot be assumed to be non-overlapping and disjoint. Thus, while the concepts of central place theory and market-area analysis often provide useful insights for organizing our perceptions of certain aspects of the structure of urban space, the use of such theory remains very much at the level of conceptual frameworks aiding analysis and falls short of providing viable techniques.

B. The Deficiencies of Present Data Analysis Methods

The search for practical methods for analysis of spatial patterns of social phenomena has held the interest of statistically-oriented methodologists within the social sciences since the beginnings of urban and regional studies. Initial attempts to analyze spatial relationships between patterns followed the ecological correlation approach using product-moment correlation techniques to quantify the extent of association among urban variables over geographic subareas of the city. Such studies have provided summary descriptions of the mean characteristics of individual subareas (census tracts, political wards, transportation zones), as well as correlations between summary variables across subareas. However, except where subarea characteristics have been displayed graphically in map format, these studies have yielded little information concerning area-wide spatial interdependence.

Early, Robinson (1950) criticized the use of ecological correlations as a basis for analysis of urban phenomena by pointing out that correlations of variables over individuals cannot be inferred from correlations computed over variables defined as characteristics of spatial groups. As Menzel (1950) has suggested, ecological correlations

may be considered meaningful where the geographically delineated populations themselves are clearly identified as the units of analysis. Still, in urban analysis it must be remembered that simple ecological correlations are in no way dependent on proximity relationships between subareas. Hence, spatial associations among patterns extending across subareas are in no way measured.

In similar fashion, more recent studies of specific cities employing variants of the social area analysis technique of Shevky and Bell (1955, 1961) focus on classification of prior delineated subareas along *a priori* sociological dimensions, independent of any consideration of spatial relationships between geographic subareas. Further, studies conducted using techniques in the tradition of ecological correlation do not in general yield results that are appropriate as data for comparative analysis of variations across urban areas. While exceptions to this rule may be argued to exist for specialized studies (for example, the study by Taeuber and Taeuber (1965) of Negro residential segregation within U.S. cities), data analysis techniques for such studies tend to be selected with respect to narrowly defined research objectives, and hence the applicability of the methods chosen for more general problems of urban spatial analysis is limited.

Summarizing and criticizing a wide variety of methods used for analysis of geographically distributed phenomena, Duncan, Cuzzort, and Duncan (1961) refer to the collection of methodological problems involved as statistical geography. They themselves propose no new solutions to the issues that they raise. Their discussion is valuable, however, in that it highlights issues surrounding the dependence of values determined by most analysis techniques on the number and size of the areal units chosen for spatial grouping of all data.

In an effort to develop methods yielding spatial associations less sensitive to the specific number and size of areal units, Warntz (1956, 1957, 1959) and others (see Neft, 1966) have approached the problem of analyzing spatial interdependence in quite a different manner.

The approach taken by Warntz and followers requires an initial transformation of all data arrayed by discrete areal units into <u>potential surfaces</u> mathematically continuous across all areal units. Then, for any two spatially distributed variables (now represented as continuous mathematical surfaces), an approximation to the true surface-to-surface correlation (the measure that would be obtained by correlating the values of potentials for the infinite set of points matched between the two surfaces) is obtained by computing a measure of surface-to-surface correlation using only a sample of points.

However, there are serious methodological questions surrounding the method proposed by Warntz for analysis of spatial data associations since there exist an infinite number of mathematically continuous surfaces that may be selected to fit a particular set of spatially distributed observations. Recognizing this condition, Warntz chooses to define his surfaces in strict analogy to the concept of <u>field potential</u> as it is employed in physics. To support this choice of a specific mathematical function, Warntz allies himself with the arguments of the "social physicist" John Q. Stewart (1947, 1948).

Stewart, like his contemporary Zipf (1949), held that there exist general laws of nature governing the macro behavior of social systems in much the same manner that the universal laws of physics govern the behavior of complex physical systems. There is much evidence to suggest that mathematical equations for macro distributions of social phenomena

can be constructed in the same form as the equations for the physical concepts of gravitational force, energy, and potential. However, there is little evidence for the existence of any universal numerical constants for such mathematical models of social phenomena analogous to the gravitational constant of physics (Isard, 1960). For example, given a new set of data on intercity travel within the U.S., the transportation planner is forced to calibrate anew his gravity model, determining empirically each time some set of parameters best-fitting the data at hand. Thus, Warntz's decision "...to cling to the purely physical notions of Newton on gravity, La Grange on potential and Stewart on social physics..." (Warntz, 1957, p. 128), from the viewpoint of the statistically-oriented social scientist, must be regarded as rather arbitrary.

Following the OPEC oil embargo of 1973-1974, there has been a wider interest on the part of academic researchers and policy makers alike in identifying those aspects of urban spatial organization that can be demonstrated to be inefficient with respect to petroleum consumption. Given the importance of the problem, it is not surprising that researchers from natural science disciplines, armed with various concepts and methods developed under the banner of mathematical ecology, have tried their hands at analyzing the efficiency of U.S. urban spatial structures.

One early analysis was offered by Watt and Ayers (1974). Obtaining comparable land use maps for 20 U.S. cities from an earlier cartographic study by Passonneau and Wurman (1966), Watt and Ayers attempted to investigate the role of land use heterogeneity as a determinant of per capita gasoline consumption rates. In light of the data and methods used, specific results obtained must be viewed as highly inconclusive if not totally meaningless.

One obvious criticism of the Watts-Ayers study concerns the appropriateness of the data selected vis-a-vis the research hypothesis to be tested. They hoped to show that for cities exhibiting highly interspersed patterns of residential, commercial, and industrial land use, persons would consume fewer gallons of gasoline in acting out their daily activity routines. However, it is known that land use *per se* is a poor indicator of socioeconomic activity, (e.g., the acreage of an industrial park by itself says little about numbers of persons commuting there to work). Though unavailable to Watt and Ayers, a better data series would have been spatial distributions of actual employment across cities by occupation and industry types. It is just this type of data that researchers can expect to have available from the files of the 1980 Census.

From our present methodological perspective, however, our criticism of Watts-Ayers focuses more sharply on the particular index of "interspersion" used to characterize urban spatial structure. The problem of measuring inter-species spatial associations in ecology is as old as the problem of defining meaningful indices of ethnic segregation in urban sociology. Methodological issues here are debated widely thoughout the mathematical ecology literature. (See, for example, the discussion by Pielou, 1969). Like simple correlation methods, most of ecological association measures depend greatly on the particular lattice used for spatially grouping observations. We conclude that, until ecologists can agree among themselves concerning the utility of inter-species spatial association indices, they should not be looked to as a source of viable methods for disentangling the dimensions of urban space.

C. Some Hope for Problem Resolution within Transportation Planning

In an early paper by Hemmens, we find a suggestion of the type of model needed for our present research purposes (Hemmens, 1967). Seeking to characterize the transportation efficiency of alternative land use-transportation system plans for a hypothetical community, Hemmens used linear programming to distribute work and shopping trips among zones, thus determining an unambiguous measure of the efficiency of each alternative. It is important to note that linear programming was used not as a simulation of travel behavior, but rather as a diagnostic instrument for determining a "best case" measure of efficiency.

Note that Hemmens could have used a gravity model or any other of several well-understood trip distribution techniques for plan efficiency analysis. However, use of any of these models would have required him to defend the accuracy of his traffic simulations. By using linear programming, Hemmens spoke only of an upper bound for transportation efficiency, and thus sidestepped all concerns related to behavioral system simulation accuracy. Concerns of this type seriously cloud the utility of most all theoretical work on normative land use planning models (for example, see Edwards, 1975.)

With respect to our present research goals, the appeal of spatial interaction models as potential mechanisms for measuring spatial efficiency stems from their relative numerical stability at different levels of geographic resolution. It is well known that the results of such models (unlike more traditional techniques of statistical geography and mathematical ecology) depend only incidentally on the number and size of zones used. Hence using these techniques to characterize the efficiency of alternative spatial patterns, we would not expect to

compute widely differing indices of efficiency for the same set of patterns represented at various levels of geography. This operational characteristic would seem mandatory for any method proposed for use in empirical study of urban spatial associations.

In a previous study by Ray (1977), logic was presented to argue that spatial interaction models of the type used for trip distribution modeling in transportation planning (e.g., gravity models, entropy maximizing models) can be used with justification as general methods for measuring spatial associations between urban population and activity patterns. Legitimate applications of spatial interaction models for this purpose have probably been suspected elsewhere. The problem has been to identify an appropriate logic to direct their application. In Ray's previous study, a particular rationale was developed employing certain information theory concepts due to Jaynes (1957) for use of a specific spatial interaction model in measuring spatial associations between distributions. For the purpose of completeness for this Study Design Report, the derivation of this model has been reproduced in Appendix A.

The basic approach views all patterns of urban phenomena (e.g., populations, activities, land uses) as discrete probability distributions defined over the subdivisions of a spatial sampling frame (e.g., city blocks, block groups, tracts.) Such a characterization of urban patterns can be argued to be sufficient, since any pattern of spatial phenomena can always be characterized as a discrete spatial probability distribution at some scale of geographic resolution. If this were not the case, for example, it would be impossible to store descriptions and to make maps of urban spatial patterns with computers.

Once spatial distributions are represented as discrete spatial probability distributions, spatial interaction models can be used to define measures of dissociation or distance between them. Here, however, the researcher is faced with the choice of a particular spatial interaction model (e.g., a specific "deterrence function," power of distance, etc.). In Appendix A it is demonstrated that, if the measure of distribution distance is constrained in form to have certain least-squares decomposition properties advocated by Bachi (1957), application of information theory concepts due to Jaynes (1957) leads to the derivation of a model of the same form as the classical gravity model as an appropriate model for characterizing inter-distribution distances.

As a preliminary test of the utility of such methods for analysis of urban structure, the following experiment was conducted. (Ray, 1977) A hypothetical city of approximately 100,000 population was designed. With respect to the basic land use transportation-infrastructure of the city, thirty-two (32) sets of urban land uses, housing types, and activity variables were distributed by hand.

Spatial associations were computed between all pairs of spatially distributed variables. This complete matrix of inter-distribution distance measures was then subjected to multidimensional scaling to obtain a geometric representation of the composite structure of associations between all variables. (It should be noted that a principal components analysis or a factor analysis of this matrix of coefficients would not be appropriate, since the strict metric properties of these measures are unknown.) As expected, the structure revealed by the scaling solution agreed closely with intuitive notions of relationships between variables. The results of a cluster analysis of these measures

agreed also with intuition. Thus, we are optimistic about the application of methods of this type for characterization of numerous aspects of urban spatial structure.

II. STUDY DESIGN REPORT

A. General Research Hypotheses

Following the rationale provided by Hemmens (1967) and Ray (1977) for use of spatial interaction models in characterizing urban spatial structure, we propose to research the costs and benefits of such spatial analysis methods for urban transportation applications. Specifically, we propose to investigate the usefulness of such methods for understanding the complexity of spatial structure within particular cities and for studying the relative efficiencies of spatial structure across cities.

For the purposes of this study, we define spatial structure efficiency simply in terms of per capita gasoline consumption. The hope is that comparative spatial analysis of population and employment distributions across cities will reveal marginal differences of spatial structure and that these differences can be shown to correlate with differences in per capita rates of gasoline consumption. In addition to the automobile, transportation choices exist to various extents across cities for travel by several modes of transit and paratransit. Thus we expect some part of per capita gasoline consumption to be related to the availability of these alternative modes of travel as well as a number of other environmental factors that we intend to control.

In the study design that follows, it is important to remember that we are proposing the use of spatial interaction models not as simulations of travel behavior giving aggregate measures of transportation demands, but rather as instruments for defining and computing meaningful distance relationships between spatial patterns. We are concerned with models of spatial interaction that have meaning in the abstract as

measures of distance between spatial distributions in general. While in some cases these models will offer as a by-product reference distributions of inter-zonal flows against which actual traffic volumes may be compared, in many other instances they will not. Thus, in other applications, we might use identical methods to characterize the extent of segregation exhibited by the housing patterns of black and white populations of a city. In this case, while the model employed is mathematically isomorphic to those used for trip distribution simulations, it would be absurd to envision a corresponding set of traffic flows (unless, of course, we are concerned with some normative issue such as cross-town busing of school children to achieve racial balance.)

Given the make up of many U.S. cities, it will not be too surprising to find that such measures of racial segregation account for some significant portion of the variance of per capita gasoline consumption. For instance, it might be hypothesized that suburban growth has been influenced over the last two decades by the desire of middle-income whites to escape the racial desegregation of central city schools. In this case the effect on per capita gasoline consumption of pattern distance between black and white populations, while significant and measurable, is indirect, i.e., it cannot be explained simply in terms of transportation interaction between the two distributions measured.

In the more typical case, however, we expect to find as significant predictors of gasoline consumption measures of distance between place of home and place of work for specific socioeconomic populations. In these cases, there will exist a more direct analogy between computations and real-world traffic volumes. In fact there is some probability that the

very model selected for abstract characterization of distance between patterns will calculate and employ a tract-to-tract joint probability matrix that is exactly proportional to real-world traffic flow. This, however, would be coincidence. The success of the method does not depend on a fit between pattern distances and mean trip lengths.

We might even find a significant inverse relationship between pattern distances and energy consumption. Consider, for example, the case of high-income CBD white collars whose residential locations, while perhaps spatially clustered, exhibit strong spatial variance. As home-to-work pattern distances for this subpopulation increase in proportion to city size, we might find a proportional decrease in per capita gasoline consumption as more and more CBD express transit services are supplied to remote high-income neighborhoods.

B. Data and Method

Over the last decade, the quality of the place-of-work, block-level coding performed by the Census Bureau in conjunction with the Journey to Work Supplement of the Annual Housing Survey has become excellent. Thus, we may expect the 1980 Census to provide a plethora of data describing daytime employment distributions in comparable fashion over all U.S. cities. Some data of this type already exist in the form of the Urban Transportation Planning Package (UTPP) files tabulated by the Census Bureau for individual metropolitan planning offices of numerous cities following the 1970 Census. Then, however, large-volume automated block-level address coding was at an early stage of development. In fact, over all of the 120 cities participating in the 1970 UTPP program,

successful block-level coding of place of work averaged only about 60 percent (Census Bureau, 1976; See also Exhibit 1. here). This condition, together with the fact that different cities resolved coding problems by different means (e.g., by coding to Zip codes, allocating miscodes), threatens seriously the legitimacy of comparative analyses of cities using the 1970 UTPP files.

The 1970 files do, however, serve as a good preliminary database for development and testing of methods for spatial analysis within metropolitan areas in preparation for 1980 Census data. Thus, we propose to obtain UTPP files for two U.S. cities that are interesting with respect to general spatial layout and gasoline consumption patterns and use pattern analysis methods to characterize quantitatively the spatial structure of each. Comparison across these two analyses would then be made at the level of a verbal discussion referencing specific sets of pairwise distribution measures computed uniformly for each of the two cities.

It is our hypothesis that these measures of spatial structure will prove useful within comparative studies of transportation efficiency across cities. To test this hypothesis using methods of statistical inference it will be necessary to have comparable employment and population patterns for a larger number of cities. For the purposes of this study, the Journey to Work Supplement of the Annual Housing Survey (AHS) provides an adequate database for such a comparative analysis. While employment distributions here are only differentiated by mode of travel to work, these total employment SMSA tract-level distributions are of good quality. Furthermore, they are comparable across all sixty (60) U.S. cities of the AHS.

We propose then to select twenty-four (24) of the forty-one (41) AHS cities where tract-to-tract files are presently available (i.e., the 1975 and 1976 SMSAs) and perform comparable pattern analyses on employment and population distributions for each. Tract-level distributions of a wide variety of population and housing variables are readily available through the Special Area Profile Tapes that were tabulated in conjunction with the Bureau's Urban Atlas project. We will test the significance of each set of specific pattern distances computed across the twenty-four (24) SMSAs as variables explaining some part of the variance of annual SMSA gasoline consumption. In doing this it will be important to control for a wide variety of alternative factors that might otherwise be experimentally confounded with our spatial structure measures.

C. Constructing an Index of Urban Spatial Efficiency

Since we wish to test the usefulness of the proposed concepts for clarifying the role of spatial structure in determining the energy efficiency of cities, it will be necessary to construct an index of spatial structure efficiency that is unambiguously defined for some appropriate sample of urban areas. This by itself will be a discrete component of the proposed research. Choosing to characterize energy efficiency primarily in terms of per capita gasoline consumption, it is required not only that we have good data concerning both daytime and nighttime populations for a sample of well-delineated urban areas, but also that we have data describing gasoline purchases by these same populations.

The availability of data suggests here again that our sample is best taken at the SMSA level. Comparable data series are available for the widest variety of variables relevant for index construction through the files of the 1970 Census and 1977 County and City Data Book at city, county and SMSA levels. At city and county levels, index construction will be plagued by severe problems related to cross-boundary daily commuting patterns. At the SMSA level, population and travel patterns for the most part become spatially separate and functionally isolable. Even at this level, however, we will wish to exclude from our index construction analyses certain SMSAs of questionable separability, e.g., the contiguous SMSAs making up the Tri-State (New York-New Jersey-Connecticut) Region.

To be strictly correct, we should take all data series from the same time period. Unfortunately, this is not possible. Exhibits 1 and 2 show the data available to our study.

The most comprehensive descriptions of population and employment distributions across U.S. cities are to be found in the data of the decennial censuses of population and housing. On the other hand, the only data that we have been able to locate describing gasoline consumption in comparable fashion across U.S. cities comes from the Census of Business. This census is quinquennial. The most appropriate data for the proposed analysis come from the 1972 and 1977 business censuses. The employment distributions are taken from the 1975 and 1976 Annual Housing Surveys.

In doing this we are making the assumption that population, employment, and gasoline consumption patterns did not change radically over the years 1970 to 1977 for the SMSAs sampled, i.e., the same factors

Exhibit 1

DATA FILES REQUIRED BY STUDY PROGRAM

Data Source	Availability
Annual Housing Survey, 1975 Travel to Work Tract Data (1 tape for 21 SMSAs)	P
Annual Housing Survey, 1976 Travel to Work Tract Data (1 tape for 20 SMSAs)	P
Census of Population and Housing,]970 Urban Transportation Planning Package (Traffic Zones) (2 tapes for 2 SMSAs)	P
Census of Population and Housing, 1970 Master Enumeration District List	A
Census of Population and Housing, 1970 Urban Atlas Tract Boundaries	A
Geographic Base File/DIME (GBF/DIME) (2 tapes for 2 cities)	P
MED List, 1970 Master Enumeration District List	A
Urban Atlas, 1970 Special Area Profiles (4 Tapes)	P
Urban Atlas Tract Boundary Files	A
Federal Highway Administration Urban Transportation Summary Statistics File	A

Legend: A = Available to RTI at TUCC through N.C. State Data Center.
P = To be purchased by project (Census Bureau available public files).

Exhibit 2

OTHER DATA FILES AVAILABLE TO STUDY PROGRAM

Data Source	Availability
Census of Retail Trade, 1972 Summary Statistic File RA	A
Census of Retail Trade, 1977 Summary Statistic File RA	A
Census of Transportation, 1977 National Travel Survey	A
County and City Data Book, 1972	A
County and City Data Book, 1977	A
County and City Data Book Consolidated File County Data, 1944-1977	A
County and City Data Book Consolidated File City Data, 1947-1977	A

Legend: A = Available to RTI at TUCC through N.C. State Data Center.

toward change were equally affecting all cities. Thus we may wish to exclude also from our sample several large cities such as Washington, D.C., where we know substantial shifts in population patterns have occurred as a result of massive downtown neighborhood revitalization processes. Otherwise, for methods development purposes, since our model focuses on patterns only as macro properties of cities, it is possible to obtain meaningful test results using the available data from different time periods.

Having selected an appropriate sample of SMSAs (N on the order of 200), we will construct an index of SMSA spatial efficiency in the following manner. The base of our index will be computed using the 1977 County and City Data Book (CCDB) files as total 1972 SMSA service station sales divided by (interpolated) 1972 SMSA populations. Needless to say, this index will require substantial adjustment before use as a measure of SMSA spatial structure efficiency. Table 1 shows this index for the forty-one (41) SMSAs of the 1975 and 1976 AHS sample.

It may be argued that differences in per capita service station sales across SMSAs are due as much or more to SMSAs differences of scale, income distribution, climate, and through traffic volumes as they are to differences of internal spatial structure. This represents the null hypothesis for all of the proposed research. The alternative hypothesis is that there exists some component of the variance of gasoline consumption that can only be explained by variation in SMSA spatial structure.

We wish to present strong evidence that the proposed concepts and methods characterize certain dimensions of spatial structure in a way that is advantageous to analyses of urban efficiency. To be maximally

Table 1

SERVICE STATION SALES PER CAPITA FOR 1975 AND 1976 AHS SMSA SAMPLE

	1970 Population (thousands) 1/	1972 Station Sales (millions) 1/	Sales Per Capita \$ (c)=(b) ÷ (a)	AHS Median Commuting Distance 2/	UTPP Rate of Coding 3/ %
	a	b	c	d	e
New York	9,974	816	82	7.9	.
Chicago	6,977	1,034	142	7.7	62
Philadelphia	4,824	622	129	7.5	40
San Francisco	3,109	480	154	7.6	62
St. Louis	2,411	405	168	8.4	60
Houston	1,999	339	170	9.2	.
Baltimore	2,071	323	156	8.8	48
Cleveland	2,064	314	152	7.8	78
Atlanta	1,596	341	214	9.8	57
San Diego	1,358	214	158	9.2	54
Miami	1,268	217	171	8.3	63
Denver	1,240	205	165	7.4	.
Milwaukee	1,404	198	141	6.1	.
Seattle-Everett	1,425	239	168	8.9	.
Cincinnati	1,387	184	133	8.4	67
Buffalo	1,349	161	119	5.5	69
Kansas City	1,274	245	192	7.8	.
San Bernardino	1,139	223	196	6.2	32
Indianapolis	1,111	223	201	7.3	.
New Orleans	1,046	142	136	5.7	70
Portland	1,007	167	166	7.5	72
Columbus	1,018	175	172	7.6	78
San Antonio	888	128	144	7.7	.
Rochester	962	145	151	6.7	70
Providence	909	123	135	5.2	66
Louisville	867	147	170	7.7	76
Sacramento	804	149	185	7.3	54
Birmingham	767	114	149	8.4	59
Oklahoma City	699	110	157	7.0	67
Hartford	721	125	173	7.0	.
Honolulu	631	83	132	6.5	52
Allentown	594	95	160	4.8	47
Omaha	543	88	162	5.4	63
Grand Rapids	539	98	182	6.1	65
Springfield	542	78	144	4.9	65
Raleigh	419	72	172	6.8	55
Paterson	461	60	130	6.9	.
Newport News	333	42	126	7.2	.
Las Vegas	273	69	253	5.8	.
Madison	290	55	190	4.9	62
Colorado Springs	239	49	205	6.8	.

Footnote: ˙SMSA not participant in 1970 UTPP program

References:

1/ 1977 County and City Data Book, Census Bureau

2/ Selected Characteristics of Travel to Work in 21 Metropolitan Areas: 1975 Census Bureau
Selected Characteristics of Travel to Work in 20 Metropolitan Areas: 1976 Census Bureau.

3/ 1970 Census Urban Transportation Planning Package Sponsors, Census Bureau (mimeo)

convincing, we must demonstrate that the proposed spatial structure measures offer some explanation of the variance of SMSA gasoline consumption that remains as a residual after component variances due to all other factors contributing to gas consumption have been subtracted. Furthermore, since the sample available for index construction by definition is constrained to approximately 200 SMSAs, we will be limited to the use of only a few of those variables in explaining SMSA station sales.

For study design purposes, we assume here that all contributing factors to our index of urban spatial efficiency may be classified into six broad categories. The first of these is, for the most part, the set of factors related to spatial structure that should not be used in index construction. These are to be tested against the index at a later stage. The remaining five are sets of factors that may be argued to influence station sales in a way that is independent of spatial order.

Among the first set of factors we have, of course, all of the various measures of spatial structure that might be computed using proposed concepts and methods. It would be inappropriate to use these measures in index construction, since it is the significance of these measures that we intend to test by the index itself. However, there exist other more traditional and more concise measures of spatial organization for which influence on SMSA gasoline consumption should be controlled. Among this latter set are measures such as total urbanized land area, density, and various population moments about the centroid. Since we have claimed that such measures by themselves are insufficient characterizations of urban spatial structure, it is appropriate in index construction to control for whatever variance of SMSA gasoline consumption may be attributed to these macro properties taken by themselves.

The Census Bureau's 1970 MED List tape will be used to calculate various population moments.

A second set of factors that must be controlled relate primarily to transportation choice characteristics of SMSA populations. SMSAs will differ widely with respect to their rates of transit ridership. Additionally, populations might be characterized in terms of proportions choosing alternative modes of commuting such as ride sharing, bicycling, and walking. While we know that the effects of such factors are to some extent confounded with the effects of elements of urban spatial structure that we intend to measure separately, the credibility of our analysis will depend on the extent to which we are able to identify the independent components of each. Hence in constructing our index of spatial efficiency, we must control for the contributions to gasoline consumption of all modal choice characteristics of SMSA populations. To do this, we will include within our analysis such variables as percent of population commuting to work by rail, bus, and alternative means--data that are available in comparable fashion across SMSAs via the 1970 Census and Federal Highway Administration summary files.

A third set of factors extraneous to the analysis will be associated with gasoline price differences across SMSAs. We will control for gasoline price differences simply by including within our analysis 1972 state and SMSA gasoline prices taken by hand from BLS Consumer Price Index (CPI) reports.

A fourth component of the true variance of per capita SMSA service station sales can be expected to be associated with disproportionate levels of SMSA through traffic, business trips, and tourism. Controlling for these components of variance within our index, we will include

variables from the 1977 County and City Data Book (CCDB) files such as total SMSA motel-hotel and restaurant receipts that we expect to serve well as proxy variables for through traffic. Also we expect several variables such as auto dealer sales and auto repair service receipts to be less sensitive to through traffic than service station sales. Thus, as negative correlates of transient gas consumption, we will include ratios of auto dealer sales to service station sales and auto repair service receipts to service station sales.

As a fifth set of factors influencing SMSA service station sales we should include within our analysis several variables related to local population characteristics and economic conditions. We expect some part of per capita gasoline consumption to be explained simply by such variables as SMSA per capita incomes and local rates of unemployment and retirement. Several variables here are available in the CCDB files.

Finally, we suspect that a sixth component of the true variance of the selected index will be explainable solely in terms of natural environmental differences across cities. Here we have in mind basic differences in climate and terrain. Controlling for the direct effects of these factors, we will test the significance of such variables as mean annual temperature ranges, mean annual frozen precipitation, and elevation ranges. These data will be taken by hand from various atlases.

After building a database containing all of the above variables, we will regress SMSA per capita sales against all independent variables. We will then construct an adjusted index of SMSA spatial efficiency (inefficiency) as that component of per capita service station sales that remains unaccounted for by the given set of variables. It is this

residual component of SMSA service station sales that we hope to explain in part by further regressions in which the proposed measures of urban spatial structure are introduced as independent variables.

D. Hypothesis Testing

Data files available through the Travel to Work supplement of the Annual Housing Survey presently provide a variety of data items describing home-to-work commuting patterns in forty-one (41) U.S. SMSAs. Since we wish to conserve wherever possible on data processing, we will exclude certain very large SMSAs from our analysis to reduce considerably data formatting and computation cost. Thus we propose to drop from our analysis the four largest AHS SMSAs, i.e., New York, Chicago, Philadelphia, and San Francisco-Oakland.

To reduce data processing costs further, we will accept for our analyses only those SMSAs included within the Urban Atlas project. This is done for two reasons. First, we expect to find the Urban Atlas SMSA reports extremely useful as a set of high quality maps against which our pattern distances may be viewed and interpreted. Second, use of the Urban Atlas Tract Boundary Files for tract geography and the Special Area Profiles Tapes for several population distributions will result in substantial data processing cost reductions. Only the Raleigh and Madison SMSAs are excluded by this restriction, leaving a total of 35 SMSAs from which to sample. From these we will select twenty-four (24) SMSAs as our sample for hypothesis testing.

To reduce further data processing costs, census tracts will be clustered to a new level of geography. We will define tract groups of

approximately four tracts each, thus reducing the size of our database by a factor of four. For example, the largest SMSA, Baltimore with 535 tracts, would be analyzed with respect to a geography of 134 tract groups. The smallest SMSA, Sacramento, with 187 tracts, would be represented in terms of approximately 48 tract groups.

We will compute centroids for all census tracts of all SMSAs using the Census Bureau's DACS algorithm and processing the Urban Atlas Tract Boundary File. These centroids will be exact only with respect to tract boundary geometry, i.e., not population. However, the calculations will be efficient. We will then use a computer plotter to map SMSAs one at a time showing only census tract numbers in the locations of computed centroids. Tracts will then be grouped by delineating by hand tract groups of approximately four each. In doing this, we may refer occasionally to the tract outline maps given in the Census Bureau's SMSA Tract Report series.

Tract groups for each SMSA will be numbered 1 through n. This information will then be keyed into the computer to form a tract equivalency list for each SMSA. With these tract equivalency lists, we will return to the Tract Boundary Files and compute centroids and land areas for all tract groups using again the DACS algorithm.

Once tract grouping is completed for each sample SMSA, selected tract level data of the Special Area Profiles Tapes and the AHS Travel to Work tract-to-tract files will be reformatted into the pattern analysis database. From the AHS tract-to-tract data, two spatial distributions of employment will be taken characterizing:

1. Employment commuting by automobile or truck (alone, carpool)
2. Employment commuting by public transportation (rail, bus, taxi)

From the Urban Atlas Special Area Profiles Tapes, two spatial distributions will be reformatted characterizing:

1. Blue collar occupations (by residence)
2. White collar occupations (by residence)

It is important to note that, for this component of the study, conservatively, we propose to analyze only four distributions. Other distributions will be analyzed as resources permit. In fact, as resources permit, we would like to analyze a much larger series of distributions characterizing the spatial structure of various socioeconomic subpopulations within each city. However, all analyses will be restricted to employment distributions tabulated from the AHS tract-to-tract summary files and population and housing distributions contained on the Urban Atlas files.

Once the database has been constructed, pattern distance measures will be computed between all pairs of spatial distributions within each SMSA. This will result in twenty-four (24) symmetric pattern distance matrices (4 x 4).

Note that, since these matrices are symmetric, only ten (1/2 (4 x 5) = 10) measures need be computed independently for each SMSA. Thus 240 (24 x 10) separate distance computations will be performed for each spatial interaction model to be evaluated.

We propose to evaluate at least three models of pattern distance, described in full in Appendix A to this proposal. These are the three models corresponding to:

1. Generalized squared distance of interaction, GDI^2 (eq. A.22, p. A-19)
2. Least mean squared distance of interaction, LDI^2 (eq. A.33, p. A-23).

3. Entropic squared distance of interaction, EDI^2 (eq. A.38, p. A-29).

Other existing association measures will be examined as resources permit. Additionally, we intend to devote some time to the research and development of alternative spatial interaction measures that are more efficient from the standpoint of computation.

Concerning the quantity of computations proposed, the following items should be noted. The GDI^2 model does not require an iterative solution technique. It may be output as an inexpensive by-product of the EDI^2 computations. The diagonal elements of the LDI^2 matrix are all known _a priori_ to be zero.

All GDI^2 and EDI^2 computations will be performed using existing IBM 360/370 FORTRAN software developed by Ray previously. Ray's work included calculation of 528 EDI^2 measures for 32 spatial distributions of a hypothetical urban area. (Ray, 1977)

All LDI^2 computations will be performed using an existing IBM 360/370 PL/1 program developed by Brandon while he was working with Ray at the University of Illinois as a graduate student (Brandon, 1979). Brandon's program is specifically designed for efficient solution of large-scale transportation linear programming problems of the type required by LDI^2. Brandon has used this program in computing 1770 LDI^2 pattern distances many of them requiring solution of linear programming problems with zone-to-zones flow matrices on the order of 150 250. This program is currently operational at RTI.

Once all pattern distance measures have been computed, they will be analyzed with respect to their usefulness in explaining variations of per capita gasoline sales across cities. Here we will also consider the median home-to-work trip length figure given in the AHS Travel to Work reports. It will be interesting to compare respectively the levels of

significance for these two independent data series as predictors of SMSA gasoline consumption. These analyses will be conducted using principally the technique of multiple regression. Other multivariate techniques will also be used (e.g., factor analysis, analysis of variance, etc.) as needed.

Among other analyses that we intend to perform will be a multidimensional scaling of all twenty-four (24) SMSAs. We will do this by computing measures of profile similarity (e.g., euclidean distance) across pattern distances for all pairs of cities. These matrices (24 x 24) of overall spatial structure dissimilarity between cities will be scaled using Young's ALSCAL program (Young, 1978). Using this same matrix, all twenty-four (24) SMSAs will be cluster analyzed. We will be looking for a configuration of cities determined by the multidimensional scaling and cluster analysis procedures that allows us to rank order and discuss all cities in terms of two or three meaningful dimensions of spatial structure. A principal components analysis will be done using these and other CCDB data. These analyses should contribute directly to our understanding of the relationship between SMSA gas consumption and spatial structure.

In addition to the above statistical analyses, we propose also to produce a set of computer plotter maps displaying graphically selected spatial distributions for each SMSA. Such mapping will serve two purposes. First, it will be a convenient way to verify that data to be processed have been accurately assembled. Second, it will provide us with a set of maps which, when compared with the maps of the Urban Atlas reports, will allow us to evaluate the effects of the loss of spatial resolution due to tract grouping.

Given the time-consuming nature of computer mapping, we propose to use for this task a relatively simple plotter program developed and employed previously at RTI. The program simply plots circles of radii proportional to tract distribution values against a background of census tract boundaries. Currently this program is being used at RTI in spatial analyses of neighborhood revitalization patterns in Washington, D.C. Since we have available for this research (through the Urban Atlas Tract Boundary Files) a complete set of census tract boundary coordinates for all SMSAs, no new database or software will be developed for this work.

We do not intend to plot each of all spatial distributions analyzed for all cities. We will display enough data, however, to have high confidence that spatial descriptions for all data series are accurate. Also we will map for all SMSAs illustrative sets of distributions found most significantly associated with variations in per capita gasoline consumption. A selected set of these maps will be reproduced in our Interim and Final reports. These maps will be selected primarily to illustrate the behavior of the various pattern distance measures computed over different SMSAs.

E. Detailed Case Studies

The comparative analysis offered above will permit testing of several hypotheses concerning U.S. urban spatial structures and per capita SMSA gasoline consumption rates. It does not, however, afford us much detail of spatial structure characterizations. Thus for any one city, it may be difficult to understand just why the per capita rate is high or low. Additionally, the data available through the AHS series do not permit demonstration of the richness of description that the 1980

Census place-of-work coding will make possible. Thus, we offer a second level of higher-resolution pattern analyses for two case study cities using 1970 UTPP data.

Restricted by the nature of our research to only two case studies, it is essential that we pick our cities well. It would be best if we could choose the two case study cities after all the results of our comparative analyses are known. Our time budget may not allow this, however, and we must be ready to select two cities based on whatever information is at hand.

Considering the spatial isolation of SMSAs and looking at the data presented in Table 1, it seems reasonable at this point to choose Grand Rapids and Rochester for our case studies.

Grand Rapids is interesting for a variety of reasons. Most notably it exhibits one of the highest service station sales to population ratios. However, its median distance of home-to-work commuting is only 6.1 miles, a figure well below the national median of 7.5-7.6 miles. Furthermore, its median commuting distance falls well below that of many cities in its same population class. These facts, together with the fact that Grand Rapids has a high rate of UTPP place-of-work coding (65%), make it a good case study choice.

Now consider Rochester. This SMSA has a respectable ratio of station sales to population and its median commuting distance 6.7 miles, is only slightly less than that of other cities of its class. Since it also participated in the 1970 UTPP program and has a high rate of UTPP block-level coding (70%), we propose it as our second case study city.

(Note: It should be understood that neither Grand Rapids nor Rochester has been contacted concerning the availability of data or the

inclination to assist RTI for the proposed analysis. If our proposal is funded, we are prepared to conduct all of our analyses using only Census Bureau public use data (which includes the UTPP files for these and all other cities so tabulated). Also, we would discuss with TSC/DOT any advantages known to TSC/DOT for substituting some other pair of cities. For Study Design Program purposes, however, we will assume throughout that the two case study cities will be Grand Rapids and Rochester.)

The UTPP file provides a wealth of data describing home-to-work commuting patterns. Our interest in these files stems from the fact that they record directly both daytime and nighttime tract-level distributions of a large sample of all persons employed within a city. Distributions are recorded at the level of transportation zones. To insure that computation costs remain within budget, we will retain the option of clustering transportation zones by hand to restrict location coding systems to some reasonable number of zone groups, say 200 to 250.

We wish to show the usefulness of the proposed methods of analysis used in conjunction with this type of data. Thus, we propose to analyze pattern distances between daytime and nighttime distributions for various subpopulations of the two case study cities. These subpopulations will be defined in terms of activity codes (occupation and industry) and broader socioeconomic characteristics (income, auto availability, etc.). Through pattern analysis of these distributions, we intend to characterize in as much detail as possible the spatial structures of the two case study communities.

We propose to analyze pattern distances among both daytime and nighttime distributions of all persons and/or groups coded for some

number (5-10) of major occupation/industry groups. The occupations from which we may choose are:

1. Professional, technical, and kindred workers
2. Managers and administrators, except farm
3. Farmers and farm managers
4. Clerical and kindred workers
5. Sales workers
6. Craftsmen and kindred workers
7. Operatives, except transport
8. Transport equipment operatives
9. Service workers, except private household
10. Private household workers
11. Farm laborers and foremen
12. Laborers, except farm

Major industry groups are:

1. Agriculture, forestry, and fisheries
2. Mining
3. Construction
4. Manufacturing
5. Transportation, communication, and other public utilities
6. Wholesale trade
7. Retail trade
8. Finance, insurance, and real estate
9. Business and repair service
10. Personal service
11. Entertainment and recreation services
12. Professional and related services
13. Public administration

Note that much information concerning land use patterns can be inferred from inspection of the daytime and nighttime distributions of these employment groups. Using these data, we expect our analysis to reveal much concerning the internal spatial structures of both case study cities.

To place descriptions of economic activity within the context of specific residential environments, we will include a number of other distributions related to the spatial clustering of household types. To characterize basic density patterns, we will include simply total population across zone groups. To characterize the patterning of various

income groups, we will include three distributions for households of low ($8,000 or less), medium ($8,000 to $20,000), and high (greater than $20,000) incomes. To describe patterns of automobile availability, we will include three distributions for households with no auto, one auto, and two or more autos.

As before in our comparative analysis, we will compute entire matrices of pattern distance relationships among distributions. The same software will be used again. Given the nature of our experiment, it is impossible to state just how large these pattern distance matrices will be, but we expect them to be in the range of 30 x 30 to 40 x 40.

These matrices also will be analyzed using methods of multidimensional scaling (MDS). It should be noted that principal components analysis and factor analysis are inappropriate tools for scaling these matrices since the strict metric properties of the pattern distances are in general unknown. Thus, MDS will be used.

It will be interesting to see what dimensions emerge for ordering our discussions of each. Which daytime occupation and industry code will group together as highly associated in space? Which will remain distant? How many dimensions will it take to characterize these real-world spatial structures? To what extent have transporation facilities influenced the character of spatial organization in these two cities?

Also, it will be interesting to compare the two case study analyses. What questions are answered concerning spatial organization within Grand Rapids and Rochester? What questions are left unanswered? What discrepancies of features between Grand Rapids and Rochester can be argued to contribute to their relative efficiencies with respect to gasoline consumption? What are the significant features of spatial structure and efficiency that public policy might control?

F. Specification of an UTPS Based Analysis System

Since we hope that the proposed pattern analysis methods will in time prove both practical and beneficial at a number of levels of transportation planning, we have to consider strategies for technology transfer. The Urban Transportation Planning System (UTPS) represents an excellent software base for implementation of pattern analysis methods for operational use in transportation policy analysis settings.

First, it might be claimed that the complete set of analyses offered here could be done at present using existing UTPS procedures. Certainly, the type of data files described (numerous series of tract-level population, employment, and housing data) are identical to those manipulated by UMATRIX procedures within UTPS. Despite all questions related to rationale and computational efficiency, the AGM procedure (or some other trip distribution model) of UTPS could be used to compute some form of distance between distributions. Presumably, certain statistical procedures of UTPS could be used in the analysis of distribution distances computed within and between urban areas.

While some of the concepts proposed could be tested using existing UTPS software, the specific Study Design Program detailed here will be undertaken relying on, for the most part, software that is independent of UTPS. Addressing the question of technology transfer, however, we will devote some of our resources to an analysis of UTPS as a software environment for pattern analysis procedures.

Specifically, we will familiarize ourselves further with UTPS and identify those components that can be applied directly (and efficiently) to specific tasks within the proposed methodology. At this point, we suspect that existing and planned UTPS subsystems for data management and file manipulation will be more than sufficient. Also, we expect to

find that existing and planned UTPS graphic display systems will suffice for pattern analysis purposes.

Systems to be added to UTPS to make available pattern analysis capabilities relate more to the efficient computation of pattern distance matrices and the structural analysis of these matrices. Since our project team has had considerable experience in designing and implementing this kind of software, we anticipate no difficulties in specifying in detail those two or three programs that must be developed to make operational within UTPS the analysis methodology proposed.

Thus, we propose no new UTPS software to be developed at this time. We do propose, however, to evaluate the potentials of an UTPS-based pattern analysis method and to specify software components and levels of effort required to make the method operational within UTPS. For estimating purposes, we anticipate that such a system could be implemented through a follow-on contract of a scale on the order of one professional manyear of development time. Given our study results, this work could be done either by RTI or by any of several software development firms familar with UTPS, or it could be done by UTPS programmers within UMTA.

III. POSSIBLE APPLICATIONS OF THE PATTERN ANALYSIS METHOD

With respect to data series and application areas, the pattern analysis method offered for evaluation is quite general. In the proposed analyses, we intend to mix together population, employment, and housing data and investigate the composite effect of all of these elements in the determination of urban spatial structure. For other studies, we might also include data more closely associated with the supply and demand of transportation facilities such as street traffic volumes, transit ridership, parking spacing, etc. Pattern analysis offers a new perspective on the spatial interdependence of all such elements. Thus, if cost effective with respect to computation, the method should prove beneficial at several levels of urban transportation planning.

At the level of national policy, we suspect that the method will be most valuable as a means for evaluating long-range effects of policy across U.S. cities. For example, it should be possible to measure across cities differences of spatial structure brought about by different mixtures of public funds for highways and transit. It might even prove possible to analyze differences of spatial structure due to specific network configurations. Past decennial censuses provide time series data to support such analyses. Super mainframe computers (e.g., ILLIAC IV, STAR) stand available to make the necessary computations should they prove necessary.

The 1980 UTPP program of the Census Bureau will provide for the first time good tract-level data describing daytime employment distributions across U.S. cities. Since social activity and land use patterns

can be easily inferred from these data, we envision a wide range of pattern analysis applications. The 1980 Census will enable a closer look at the relationship between place of home and place of work. Since we know that variation of spatial structure exists, the problem becomes one of measuring this variation systematically and, through public policy, to influence benefically future variation.

The pattern analysis method proposed seems to provide a valuable means for systematizing empirical research results concerning the interdependence of transportation for spatial structure across cities. Specific policy issues to be served by such research include the role of spatial structure in energy conservation, current trends of slowed suburban growth and downtown neighborhood revitalization, as well as shifting minority housing patterns. Also relevant to national policy making is empirical study of the manner in which the current spatial structure of U.S. cities is changing in response to substitutions throughout society of communication technologies for transportation.

At state and local levels of policy and planning, specific application of the methods proposed can also be conceived. As petroleum supplies become more uncertain, there are requirements for public policy regarding fuel allocations over counties and cities. Such policy will only be equitable to the extent that all factors determining fuel needs are systematically considered. Spatial structure may well figure heavily in these needs. How will gasoline allotments within states be decided across cities and counties?

Even at the local level, we can conceive of transportation planning agencies employing pattern analysis concepts and methods in carrying out their functions. Use here would be concerned primarily with measurement

of existing spatial structure and evaluation of the effects of alternative transportation plans. Pattern analysis concepts provide a way to systematize descriptions of changes in spatial structure over time. To the extent that these descriptions may be related to observed patterns of transportation demands, they may be used throughout transportation planning to assist in shaping the scale and efficiency of future urban environments.

IV. MASTER PROGRAM SCHEDULE

A. Study Design Program Items and Tasks

Exhibit 3 shows a functional organization of the proposed program of research where the Study agenda has been broken down into major Items and Tasks.

Item I will be concerned with analysis of numerous variables influencing per capita gasoline service station sales across U.S. SMSAs in ways extraneous to urban spatial structure. This Item is subdivided into three Tasks.

Task I.A will involve assembling all data, data keying, and processing work necessary to put together on a single file all variables that are expected to play some role in explaining gasoline consumption patterns across SMSAs. Variables from the 1977 County and City Data Book file will represent the core of the database. To this will be added various data elements of Federal Highway Administration summary statistics files. Several data elements will also be taken by hand from CPI reports and various atlases.

Task I.B will involve the analysis of this data to determine which spatial factors influence gasoline consumption across U.S. SMSAs. Considering the results of these analyses, new variables will be added to the database in an attempt to explain a larger portion of SMSA per capita station sales.

Task I.C will concern analysis of the effect of macro spatial features of SMSA spatial organization on SMSA gasoline consumption. Using the X,Y coordinates and raw population figures for block groups and enumeration districts wtihin each SMSA, a series of population

Exhibit 3

STUDY DESIGN PROGRAM ITEMS AND TASKS

Item I. Spatial Efficiency Index Analysis

- Task A. Formatting the Database
- Task B. Analysis of Alternative Factors
- Task C. Spatial Efficiency Index Construction

Item II. Testing the Study Design Hypothesis

- Task A. Formatting the Database
- Task B. Computer Maps of Population/Employment Distances
- Task C. Population/Employment Pattern Distance Computations
- Task D. Analysis of Significant Pattern Distances
- Task E. Multidimensional Scaling of Pattern Distances
- Task F. Interim Report

Item III. Detailed Case Studies

- Task A. Formatting the Database
- Task B. Computer Maps of Population/Employment Distances
- Task C. Population/Employment Pattern Distance Computations
- Task D. Multidimensional Scaling of Pattern Distances

Item IV. Specification of UTPS Based Pattern Analysis System

Item V. Final Report

moments and other statistics related to population distribution and density will be computed. The influence of these variables on station sales will be evaluated. A criterion of spatial efficiency will be established as that residual of per capita sales that remains unexplained by all of the above factors.

Item II will cover all tasks related to the comparative study of spatial structure features across twenty-four (24) SMSAs.

In Task II.A we will select the SMSA sample and cluster tracts into tract groups for each SMSA, using the method outlined in the Study Design Report. Using the Urban Atlas Tract Boundary Files we will compute the centroids and land area for all tract groups. Daytime SMSA employment distributions across tract groups (and tracts) will be tabulated from the Annual Housing Survey 1975-1976 Travel to Work tract data. SMSA population and housing distributions will be taken directly from the Urban Atlas Special Area Profiles Tapes.

Task II.B will involve computer mapping of the data extracted in Task 2.A to insure its accuracy. Corrections to tract group geometry and distribution data will be made as necessary. Following analysis of this data, a series of maps of significant distributions will be made for inclusion into research reports.

Task II.C will concern the computation of GDI^2, LDI^2, EDI^2 and other measures of distance between distributions within SMSAs.
For all twenty-four (24) SMSAs, GDV^2, LDI^2, and EDI^2 measures will be computed for at least all pairs of the four employment and population distributions discussed in the Study Design Report. Resources permitting, several SMSAs will be analyzed in more detail, computing pattern distances for a larger number of population and housing distributions.

This will be primarily a data processing operation using non-proprietory software developed earlier by Ray (1977) and Brandon (1979). Resources permitting, other measures of distance between patterns will be computed.

Task II.D will focus on our analysis of the computed pattern distances as predictors of SMSA gasoline consumption. Pattern distances will be entered into multiple regression models explaining station sales as a function of these spatial structure variables as well as other aspatial variables. Both stepwise and stagewise regression models will be used. Using these techniques, a comparison will be made between the computed pattern distances and the median home-to-work distances given by the AHS Travel to Work reports.

Task II.E will investigate the use of multidimensional scaling procedures as a method of analyzing differences in spatial structure between the SMSAs of our sample. Profile similarity measures will be computed pairwise for all SMSAs. The resulting similarity matrices will be scaled using Young's ALSCAL program. (1979) Resources permitting, pattern distances between numerous distributions (16-24) for selected SMSAs of our sample will have been computed. These pattern distance matrices will then be scaled individually to analyze differences of spatial structure between the several SMSAs of the more detailed analysis. If a sufficiently large number of SMSAs can be analyzed in this manner, the INDSCAL model of Carroll and Chang (1970) will be used to scale all distance matrices simultaneous in characterizing individual differences between SMSAs.

Task II.F represents the preparation of an Interim Report describing all analysis results determined thus far in the Study. This report

will focus on a discussion of all variables found significant in explaining SMSA station sales. It will offer a tentative evaluation of the use of pattern analysis methods for characterizing and estimating the efficiency of alternative urban spatial structures.

Item III will focus on an evaluation of pattern analysis methods as instruments for detailed analysis of urban spatial structure. Two cities will be analyzed as case studies.

Task III.A will require processing the data of the Urban Transportation Planning Package (UTPP) files for these two cities to establish the required database. For the most part, spatial distributions to be analyzed will be taken from the UTPP files and recorded in the database with respect to transportation zones. Zones will be grouped by hand where necessary to obtain a system of no more than 200 to 250 subareas. Block equivalency files listing all 1970 Census blocks within each UTPP zone will be matched against GBF/DIME files to determine the boundaries, areas, and centroids for all zones (zone groups). Spatial data series from other files may be entered into the database where they carry geocodes relating to 1970 Census geography.

Task III.B will entail the plotting of zone boundaries, centroids and selected data elements to verify the correctness of zone representations and data series. Selected data series will be mapped for inclusion into the Final Report.

Task III.C will entail the computation of pattern distance measures for numerous employment, population, and housing data series. Again, for each distribution pair, several alternative measures will be computed.

Task III.D will involve a multidimensional scaling (MDS) of all pattern distances calculated in Task III.C. We anticipate distance

matrices on the order of 30 x 30 to 40 x 40 to be available for scaling. Since there will be several matrices for each case study corresponding to the several pattern distance models used, it will be possible to evaluate the different models *vis à vis* each other with respect to their characterizations of spatial structure. Also, a comparison will be made between the spatial structures revealed by the MDS solutions for the two case study cities.

Item IV will focus on an evaluation of the data management and graphic display subsystems of the Urban Transportation Planning System (UTPS) as a software base for supporting pattern analysis through UTPS. With reference to the results of research in Items I, II, and III above, system recommendations will be formulated. Where new UTPS software seems appropriate, details will be provided to describe methods, algorithms, and computational techniques known to the Study team. However, no explicit development of UTPS software will be undertaken in this Item or in any other Item of this Master Program Schedule.

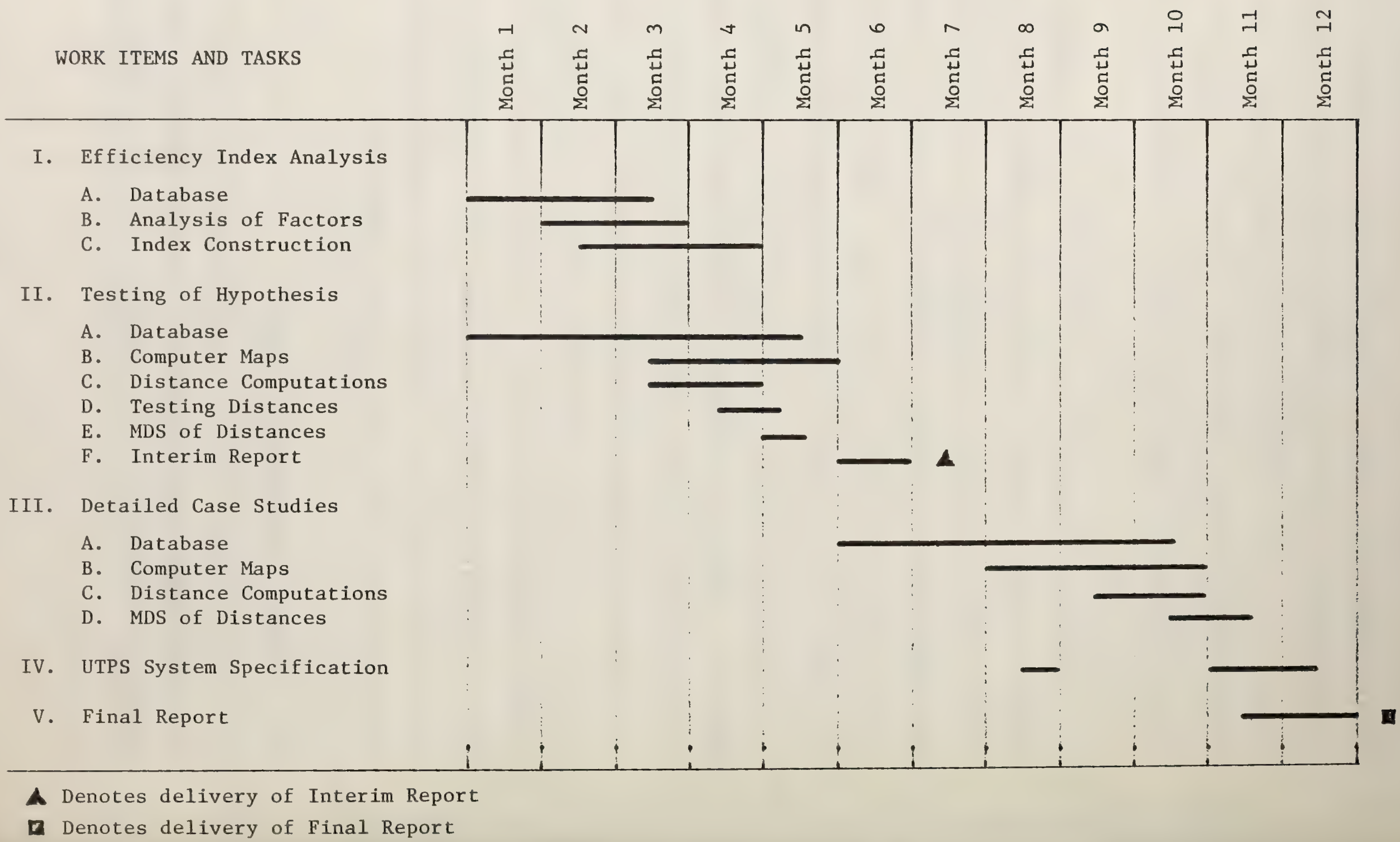
Item V represents the Final Report to be prepared in the last (twelfth) month of the Study. The Final Report will incorporate all research findings in Items I, II, III, and IV above. It will draw on some of the material already reported in the Interim Report. This document will also convey to DOT/TSC all recommendations concerning implementation of UTPS pattern analysis capabilities.

B. Periods of Performance for Tasks

Exhibit 4 shows the time periods in which all Tasks of all Master Program Schedule Items will be undertaken and completed. This exhibit assumes a twelve-month contract period with Month 1 starting upon award of contract.

Exhibit 4

PERIODS OF PERFORMANCE FOR ALL TASKS AND THE DATES FOR ALL REPORTS



Pages 47 through 61 have been deleted.

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APPENDIX A

A MATHEMATICAL APPROACH TO MEASUREMENT OF DISTANCE BETWEEN URBAN SPATIAL DISTRIBUTIONS

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A MATHEMATICAL APPROACH TO MEASUREMENT OF DISTANCE BETWEEN URBAN SPATIAL DISTRIBUTIONS

A. Introduction

In this appendix we focus on our primary methodological objective, namely the specification of more general methods for quantitative characterization of urban spatial organization as a complex system of differentiated population, activity, and land use patterns. Our focus is on the city as a system of geographically patterned phenomena. We are concerned with social behavior only to the extent that macro behavior patterns may be suggested by specific geographic configurations of populations and activity locations. Our main objective is the development of alternative measures better equipped for analysis of the spatial interdependence exhibited by patterns of urban phenomena and the role of transportation and spatial structure in determining the energy efficiency of U.S. cities.

Four major problems confront us within this measurement task. The first problem is that of representing specific urban patterns as discrete areal distributions characterizing essential properties of the phenomena of interest. The two basic issues here concern the choice of a set of variables for point-by-point measurement of patterned phenomena, and the choice of a frame of area units for use as a basis for spatial aggregation of all measurements. A second problem concerns quantitative characterization of overall distribution properties.

Common measures used here include the geographic coordinates of distribution centroids as measures of central tendency and various statistical moments about these centroids as measures of distribution dispersion. A third problem involves the measurement of spatial association between differentiated urban distributions. It is by such measures that inferences about the ecological interdependence of distributions can be made. Finally, a fourth problem involves analysis of the structure of associations among areal distributions. It is here that we hope to derive quantitatively those syntactical regularities of urban space that are exhibited in comparable manner across cities.

It should be noted that these four problems confounding the analysis of geographic patterns of urban phenomena are highly interrelated. Most importantly, the utility and validity of all analysis results will depend on our choice of specific data series and our selection of a particular geographic frame for representation of all patterns. Of course, we should select that set of available variables most closely identified with the specific urban phenomena we wish to analyze. Given that discrete representations of patterns will inevitably depend to some extent on the particular system of zonal units selected for data aggregation, we must expect our analysis results to depend to some extent on the spatial sampling frame as well. Here, the best we can do is to choose a system of zones of sufficiently fine resolution that it captures the essential characteristics of all patterns of interest. Just as important, we should employ only methods whose measures depend only incidentally on the specific dimensions and subdivisions of the particular frame selected.

Most methodological issues confronting the quantitative characterization and analysis of urban spatial patterns come sharply into focus if we recall the distinction between parametric and non-parametric statistical distributions. A parametric distribution is a probability series that may be completely specified with reference to some number of numerical parameters quite small relative to the potentially infinite set of data values associated with the distribution itself. For example, if a univariate distribution is known to be normal, then the entire distribution is completely characterized by only two parameters, i.e., its mean and its variance. On the other hand, if the distribution is known to be non-parametric and not well approximated by any known parametric distribution then, while we may compute any number of summary statistics and moments based on discrete samplings of the distribution, these measures may assist us little in characterizing the overall nature of the distribution itself.

It is one of the fundamental premises of this study that geographic patterns of urban phenomena cannot in general be adequately approximated in terms of bivariate parametric distributions. Thus, we contend that the most appropriate characterization of any specific pattern is given by the complete representation of the pattern itself, i.e., its representation as an areal distribution of some measurable variable whose value is recorded across a complete frame of spatial sampling units. This is not to argue that there exist no summary measures of overall distribution properties of value. The issue is, rather, just what overall distribution properties, in addition to such properties as central tendency and dispersion, should we attempt to quantify. For example, it would seem desirable to have some measure of the overall spatial

complexity associated with a particular distribution. Here, with respect to the problem of unambiguous definition of such a concept as spatial complexity, the position we shall assume is that whatever concept we employ, like the concept of distribution variance, will only be definable in mathematical terms.

In the remainder of the pages of this appendix, we outline an alternative approach to the analysis of urban spatial distributions that addresses in unified mathematical format all of the methodological issues discussed above. Based on a maximum-entropy formulation of spatial relationships among areal distributions, the model yields a variety of measures useful for quantitative characterization of certain aspects of intra-distribution spatial complexity and organization and inter-distribution spatial association. Surprisingly enough, the model also yields a new technique for hierarchical cluster analysis of areal distributions (see Ray, 1977).

B. Characterization of Urban Patterns as Areal Distributions

Like all other methods used for analysis of geographically distributed socioeconomic data, the methods that we propose here depend in a fundamental way on the manner by which we characterize urban patterns as discrete areal distributions. Of course, we assume the existence of measurable variables closely identified with all phenomena of interest. In many instances, however, due to data collection costs, confidentiality restrictions, or qualitative judgements in codification, we are forced to settle for only proxy variables.

A more ambiguous collection of methodological issues surrounds our choice of a specific system or frame of areal subdivisions of an

urban area for use as a common basis for aggregation of all data and representation of all patterned phenomena as discrete areal distributions. The analysis methods that we will develop here require that we select our spatial sampling frame with respect to three general sets of conditions.

First, some a priori delineation of the outer boundaries of an urban area is required. Then it is assumed that the subdivisions of the area are non-overlapping and cover exhaustively the complete urban area. Thus, each data measurement will fall within one and only one geographic areal unit or tract. Further, the tabulation (or statistical estimation) of aggregate variable values across all tracts should comprise sufficient information for representation of urban patterns as area-wide probabilistic distributions.

Second, it is assumed that areal units are of sufficient number and scale to capture the essential spatial properties of all patterns of interest. This condition concerns the spatial resolution of the sampling frame employed. At too coarse a level of resolution, spatial pattern features of interest will be lost. For example, if we wish a detailed characterization of the pattern of neighborhood commercial establishments throughout an urban area, a sampling frame of relatively fine resolution must be employed. On the other hand, if we are concerned only with the pattern of major centers of commercial activity, then a much coarser sampling frame will do.

Third, it is assumed that all areal units are compact in shape. While we do not require a regular grid, no tract should be overly elongated in any one direction or curvilinear. This condition arises as a result of two basic requirements of our mathematical model. First,

it is important that the centroids of individual tracts represent good approximations (relative to tract sizes) of the point locations of all variable measurements taken within tracts. Second, we wish geographic coordinate pairs for points within tracts to be uncorrelated and to remain uncorrelated over rotational transformations of coordinates.

Where all of these conditions are met within the specification of a frame of areal units, for the purposes of our modeling strategy, the complete frame itself may be represented numerically in the following manner. We first establish a planar geographic coordinate system having x and y orthogonal axes and origin fixed relative to the geography of the urban area. Any unit of length convenient for expression of distances (miles, kilometers) may be selected for coordinate intervals.

Now let there be n tracts comprising the frame and let all tracts be permanently numbered 1 through n. Associated with each tract i will be four descriptive constants: Mx_i, My_i, Vx_i, and Vy_i. Mx_i and My_i represent the coordinates of the centroid of the i-th tract taken with respect to the established x,y coordinate system. Vx_i and Vy_i represent x and y component variances associated with a uniform distribution of points over the area defined by the i-th tract. Note now that our numerical representation of the complete frame of areal units is simply an array of summary measures describing the positions and sizes of all n tracts. The x and y centroid coordinates of all tracts are taken as measures of their relative positions, and, since we have assumed compactness for all tracts, the x and y component variances of intra-tract point distributions are closely proportional to the squares of x and y tract dimensions.

Our requirement that all tracts be compact in shape will, of course, imply that the values of Vx_i and Vy_i for each tract will not differ by much. Thus, it will be convenient for many analyses to simply assume that $Vx_i = Vy_i$ for all $i=1,\ldots,n$ and reduce the number of descriptive constants for each tract from four to three. It will facilitate our mathematical discussion here, however, to maintain separate notations for Vx_i and Vy_i.

Having described our method for selecting a specific spatial sampling frame and representing it numerically, it remains only to be said that all patterns of urban phenomena will be represented as discrete probability distributions of specific variables across the set of tracts comprising the frame. For maximum generality, we will assume that data values for all geographic patterns to be analyzed have been measured, either explicitly or implicitly, over all tracts. Thus, any particular spatial distribution may be represented mathematically as a vector ${}_fZ$ of n elements where n is the number of areal units, f denotes the particular areal distribution, and the elements ${}_fz_i$, $i=1,\ldots,n$, are probabilities proportional to the aggregated data values recorded for each of the n areal units. Thus, ${}_fz_i \geq 0$ for all i and for all f, and $\Sigma_i^n \, {}_fz_i = 1$ for all f.

One further note concerning vocabulary is appropriate. We will occasionally find it convenient to speak of the elements of an areal distribution. By the term <u>elements</u> of a distribution, we intend generally to denote those areal units or tracts having non-zero quantities of the variable measured in representing some pattern of phenomena as a discrete areal distribution. For maximum mathematical generality, however, we will preserve the option of characterizing all distributions

as consisting uniformly of n elements (n the total number of tracts) where each particular probability vector ${}_fZ$ may contain numerous zero elements.

C. Basic Measures of Central Tendency and Dispersion for Areal Distributions

For a given areal distribution f, let ${}_f\bar{M}x$ and ${}_f\bar{M}y$ denote the x and y coordinates of the centroid or "center of gravity" of the distribution considered as a whole. These distribution centroid coordinates are defined by the formulas:

(A.1) $${}_f\bar{M}x = \sum_i^n {}_fz_i \, Mx_i \quad ,$$

(A,2) $${}_f\bar{M}y = \sum_i^n {}_fz_i \, My_i \quad ,$$

where again the Mx_i's and My_i's are constants over all distributions representing the x and y centroid coordinates of all n individual areal units comprising the spatial sampling frame. Thus, ${}_f\bar{M}x$ and ${}_f\bar{M}y$ are measures of distribution central tendency. As such, they represent the average position or mean spatial coordinates for all point locations of phenomena associated with the particular distribution f.

Now let ${}_f\bar{V}x$ and ${}_f\bar{V}y$ denote the two component variances associated with the same areal distribution f measured with respect to the x and y frame axes. We may then take as a generalized measure of overall spatial distribution dispersion the quantity

(A.3) $${}_fDV = {}_f\bar{V}x + {}_f\bar{V}y \quad .$$

Following Neft (1966, p. 55), we will refer to this measure ${}_f DV$ as the distance variance associated with the areal distribution f.

Let us consider in turn the two component variances ${}_f\bar{V}x$ and ${}_f\bar{V}y$ associated with f. From the definition of variance, we have

$$ {}_fVx = E({}_fCx^2) - [E({}_fCx)]^2 $$

where ${}_fCx$ is a random variable denoting the x coordinate of any randomly selected point of occurrence of phenomena contributing to the distribution f. Clearly, $[E({}_fCx)]^2 = {}_f\bar{M}x^2$. This condition, together with certain additivity properties of expectation, allow us to write

$$ \text{(A.4)} \qquad {}_f\bar{V}x = \sum_i^n {}_fz_i \, E({}_fCx_i^2) - {}_f\bar{M}x^2 \quad . $$

Considering the random variable ${}_fCx_i^2$, note that

$$ E({}_fCx_i^2) = E[({}_fCx_i - Mx_i) + Mx_i]^2 \quad , $$

$$ = E[({}_fCx_i - Mx_i)^2 + Mx_i^2 + 2Mx_i({}_fCx_i - Mx_i)] \quad , $$

and since $E[2Mx_i({}_fCx_i - Mx_i)] = 0$,

$$ \text{(A.5)} \qquad E({}_fCx_i^2) = Mx_i^2 + Vx_i $$

where Vx_i denotes the potential residual variance to be associated with the random variable ${}_fCx$ to the extent that the randomly selected point may be assumed to lie within the i-th tract. Clearly this potential residual variance is exactly that same numerical constant of intra-tract component variance ascribed to tract i above in our numerical representation of the complete spatial sampling frame. Then by substitution

of (A.5) into (A.4) and noting that ${}_f\bar{M}x^2 = \Sigma_i^n \, {}_fz_i \, \bar{M}x^2$, we may write

$$
\begin{aligned}
{}_f\bar{V}x &= \sum_i^n {}_fz_i \left[Mx_i^2 + Vx_i - {}_f\bar{M}x^2\right] \quad , \\
&= \sum_i^n {}_fz_i \left[Mx_i^2 + {}_f\bar{M}x^2 - 2\,{}_f\bar{M}x \sum_j^n {}_fz_j \, Mx_j + Vx_i\right] \quad , \\
&= \sum_i^n {}_fz_i \left[(Mx_i - {}_f\bar{M}x)^2 + Vx_i\right] \quad ,
\end{aligned}
$$

(A.6) $$= \sum_i^n {}_fz_i \, (Mx_i - {}_f\bar{M}x)^2 + \sum_i^n {}_fz_i \, Vx_i \quad .$$

In an identical manner, it may be shown that

(A.7) $${}_f\bar{V}y = \sum_i^n {}_fz_i \, (My_i - {}_f\bar{M}y)^2 + \sum_i^n {}_fz_i \, Vy_i \quad .$$

Together (A.3), (A.6), and (A.7) imply

(A.8) $${}_fDV = \sum_i^n {}_fz_i \left[(Mx_i - {}_f\bar{M}x)^2 + (My_i - {}_f\bar{M}y)^2\right] + \sum_i^n {}_fz_i \left[Vx_i + Vy_i\right]$$

This demonstrates that distance variance as a general measure of overall distribution dispersion may always be decomposed into two distinctly different components, one determined by the probability vector ${}_fZ$ in conjunction with the spatial coordinates of tract centroids and the other determined by ${}_fZ$ in conjunction with the residual variances associated with intra-tract point distributions.

D. An Alternative Method for Computing the Distance Variance of a Distribution

In this section we wish to demonstrate a method for computing the distance variance of an areal distribution in a manner that is independent of the centroid coordinates of the distribution. To do this, we must first construct a symmetric matrix S (n x n) where any element $s_{i,j}$ represents the expected squared euclidean distance between any two point locations within our urban area, one point being taken within the i-th tract and the other taken within the j-th tract.

Let the random variable representing the expected squared distance between any pair of points of the i-th and j-th tracts be denoted $E(D^2_{i,j})$. Given the additivity of squared distance components along orthogonal axes, we may express $E(D^2_{i,j})$ alternatively as $E(Dx^2_{i,j} + Dy^2_{i,j})$ where $Dx^2_{i,j}$ and $Dy^2_{i,j}$ are themselves random variables representing squared distance components along the orthogonal x and y axes. Furthermore, given the fact that the expectation of a sum of random variables is equal to the sum of the expectations of the random variables taken individually, we may note that $E(D^2_{i,j}) = E(Dx^2_{i,j}) + E(Dy^2_{i,j})$.

Now consider simply the random variable $E(Dx^2_{i,j})$ which represents the expected squared distance component along the x axis. Let Cx_i denote the x coordinate of the point taken within the i-th tract, and, similarly, let Cx_j denote the x coordinate of the point taken within the j-th tract. As discussed above, Mx_i and Mx_j denote the mean x coordinates of all points distributed uniformly thoughout the i-th and j-th tracts respectively. Then it follows that

$$E(Dx^2_{i,j}) = E[(Cx_i - Cx_j)(Cx_i - Cx_j)] \quad ,$$

$$= E(Cx^2_i) + E(Cx^2_j) - 2E(Cx_i Cx_j) \quad ,$$

and since the random variables Cx_i and Cx_j are assumed to be independent,

$$E(Dx^2_{i,j}) = E(Cx^2_i) + E(Cx^2_j) - 2E(Cx_i)E(Cx_j) \quad ,$$

(A.9) $$= E(Cx^2_i) + E(Cx^2_j) - 2Mx_i Mx_j \quad .$$

Now with reference to (A.5) we know that

(A.10) $$E(Cx^2_i) = Mx^2_i + Vx_i \quad ,$$

and similarly

(A.11) $$E(Cx^2_j) = Mx^2_j + Vx_j \quad .$$

Together, equations (A.9), (A.10), and (A.11) imply

$$E(Dx^2_{i,j}) = (Mx^2_i + Mx^2_j - 2Mx_i Mx_j) + Vx_i + Vx_j \quad ,$$

$$= (Mx_i - Mx_j)^2 + Vx_i + Vx_j \quad .$$

In identical fashion, it may be shown that

$$E(Dy^2_{i,j}) = (My_i - My_j)^2 + Vy_i + Vy_j \quad .$$

Now, from above, we know that $E(D^2_{i,j}) = E(Dx^2_{i,j}) + E(Dy^2_{i,j})$. Also, it is clear that the squared distance between centroids of the i-th and j-th tracts is exactly the sum $(Mx_i - Mx_j)^2 + (My_i - My_j)^2$.

Thus, it may be easily verified that the expected squared distance between any two points in our city, one taken from the i-th tract and the other from the j-th tract, is simply the squared distance between the centroids of the two tracts augmented by the sum of four additional terms: namely, the four component variances associated with the distributions of points within the two tracts relative to the x and y axes.

Thus, the following representation of our S matrix is suggested. Let ${}_bS$ denote an n x n symmetric matrix where each element ${}_bs_{i,j}$ represents the squared euclidean distance <u>between</u> the centroids of the i-th and j-th tracts. Here, of course, ${}_bs_{i,j}>0$ for all $i\neq j$ and ${}_bs_{i,j}=0$ for all $i=j$ according to:

(A.12) $${}_bs_{i,j} = (Mx_i - Mx_j)^2 + (My_i - My_j)^2 \quad .$$

Also, let ${}_wS$ denote an n x n symmetric matrix where each element ${}_ws_{i,j}$ represents that additional sum of intra-tract component variances necessary to account for the total expected squared distance between point pairs of i and j due to our lack of knowledge concerning the exact locations of the two points <u>within</u> the two tracts. In this case, ${}_ws_{i,j}>0$ for all $i=j$ as well as all $i\neq j$ according to:

(A.13) $${}_ws_{i,j} = Vx_i + Vx_j + Vy_i + Vy_j \quad .$$

Then, clearly

(A.14) $$s_{i,j} = {}_bs_{i,j} + {}_ws_{i,j} \qquad i,j = 1,\ldots,n.$$

Now following Neft (1966), Bachi (1957), and others, for a given areal distribution f with centroid coordinates ${}_f\bar{M}x$ and ${}_f\bar{M}y$, let us define as an alternative measure of dispersion the <u>generalized distance variance</u>:

(A.15) $$ {}_fGDV = \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \; s_{i,j} \quad . $$

Given that $s_{i,j} = {}_ws_{i,j} + {}_bs_{i,j}$, $i,j=1,\ldots,n$, we may always decompose ${}_fGDV$ into between-element and within-element components in accordance with

$$ {}_fGDV = {}_{(w)f}GDV + {}_{(b)f}GDV \quad , $$

$$ = \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \; {}_ws_{i,j} + \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \; {}_bs_{i,j} \quad . $$

Considering first the expression for ${}_{(b)f}GDV$, note that

(A.16) $$ {}_{(b)f}GDV = \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \left[(Mx_i - Mx_j)^2 + (My_i - My_j)^2\right] $$

$$ = \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \; (Mx_i^2 + Mx_j^2 - 2Mx_iMx_j) $$

$$ + \sum_i^n \sum_j^n {}_fz_i \; {}_fz_j \; (My_i^2 + My_j^2 - 2My_iMy_j) \quad . $$

This formulation demonstrates that the between-element component of generalized distance variance itself may always be decomposed further into additive x and y components in accordance with

(A.17) $$ {}_{(b)f}GDV = {}_{(b)f}GDVx + {}_{(b)f}GDVy \quad . $$

For mathematical convenience, let us assume a translation of all tract coordinates of the form $M'x_i = Mx_i - {}_f\bar{M}x$ and $My'_i = My_i - {}_f\bar{M}y$ so

that the centroid of the distribution f is now at the frame origin. Then, $\Sigma_i^n \, {}_f z_i \, M'x_i = \Sigma_i^n \, {}_f z_i \, (Mx_i - {}_f\bar{M}x) = 0$, and $\Sigma_i^n \, {}_f z_i \, M'y_i = \Sigma_i^n \, {}_f z_i \, (My_i - {}_f\bar{M}y) = 0$. Clearly, all elements $s_{i,j}$, ${}_w s_{i,j}$, and ${}_b s_{i,j}$ would be invariant to such a translation of coordinates.

With reference to (A.16) and (A.17), note that ${}_{(b)f}GDVx$ may now be expressed as

$$ {}_{(b)f}GDVx = \sum_i^n \sum_j^n {}_f z_i \, {}_f z_j \, (M'x_i^2 + M'x_j^2 - 2M'x_i Mx_j) \text{ or,} $$

(3.18)
$$
\begin{aligned}
{}_{(b)f}GDVx = & \sum_i^n \sum_j^n {}_f z_i \, {}_f z_j \, (Mx_i - {}_f\bar{M}x)^2 \\
& + \sum_i^n \sum_j^n {}_f z_i \, {}_f z_j \, (Mx_j - {}_f\bar{M}x)^2 \\
& - 2 \sum_i^n \sum_j^n {}_f z_i \, {}_f z_j \, (Mx_i - {}_f\bar{M}x)(Mx_j - {}_f\bar{M}x) \quad .
\end{aligned}
$$

The last term of (A.18) will always be 0 since, by manipulation of terms, it may be written in the format $-2[\Sigma_i^n \, {}_f z_i \, (Mx_i - {}_f\bar{M}x)][\Sigma_j^n \, {}_f z_j \, (Mx_j - {}_f\bar{M}x)]$ and $\Sigma_i^n \, {}_f z_i \, (Mx_i - {}_f\bar{M}x)$ is clearly 0. Minor additional manipulation permits us to write

$$ {}_{(b)f}GDVx = \sum_i^n {}_f z_i \, (Mx_i - {}_f\bar{M}x)^2 + \sum_j^n {}_f z_j \, (Mx_j - {}_f\bar{M}x)^2 $$

which, with reference to (A.6), yields

$$ {}_{(b)f}GDVx = {}_f\bar{V}x - \sum_i^n {}_f z_i \, Vx_i + {}_f\bar{V}x - \sum_j^n {}_f z_j \, Vx_j \quad . $$

In identical fashion, it may be shown that

$$ {}_{(b)f}GDVy = {}_f\bar{V}y - \sum_i^n {}_f z_i \, Vy_i + {}_f\bar{V}y - \sum_j^n {}_f z_j \, Vy_j \quad . $$

Thus, via (A.17), we have

$$(3.19) \qquad {}_{(b)f}GDV = 2({}_f\bar{V}x - \sum_i^n {}_fz_i\ Vx_i + {}_f\bar{V}y - \sum_i^n {}_fz_i\ Vy_i) \quad ,$$

$$= 2\ {}_fDV - 2(\sum_i^n {}_fz_i\ Vx_i + \sum_i^n {}_fz_i\ Vy_i) \quad .$$

Now, let us consider the within-element component of our generalized distance variance measure and, with reference to (A.13), write

$$_{(w)}GDV = \sum_i^n \sum_j^n {}_fz_i\ {}_fz_j\ {}_ws_{i,j} \quad ,$$

$$= \sum_i^n \sum_j^n {}_fz_i\ {}_fz_j\ (Vx_i + Vx_j + Vy_i + Vy_j) \quad ,$$

$$= \sum_i^n {}_fz_i\ (Vx_i + Vy_i) + \sum_j^n {}_fz_j\ (Vx_j + Vy_j) \quad .$$

Since our summations here take place over the same set of terms, we may rearrange the order of our summations and write simply

$${}_{(w)f}GDV = 2(\sum_i^n {}_fz_i\ Vx_i + \sum_i^n {}_fz_i\ Vy_i) \quad .$$

But this is precisely the quantity by which ${}_{(b)f}GDV$ differs from $2\,{}_fDV$ in (A.19). Hence, given that ${}_fGDV = {}_{(b)f}GDV + {}_{(w)f}GDV$, we have the major result:

$$(A.20) \qquad {}_fGDV = 2\,{}_fDV \quad .$$

By its definition in (A.15), the generalized distance variance ${}_fGDV$ for for any distribution f may be computed solely in terms of the probability vector ${}_fZ$ associated with f and our matrix S of inter-point expected squared distances which is determined solely by our choice of a specific

sampling frame. Additionally, from (A.20) above, we know that the distance variance of a distribution f is related to its generalized distance variance by

$$_f DV = \tfrac{1}{2}\, _f GDV \quad .$$

Thus, we have demonstrated that the distance variance of any specific distribution f may also be computed directly from $_f Z$ and the matrix S in a manner independent of the coordinates of the distribution's centroid. Specifically,

$$(A.21) \qquad _f DV = \tfrac{1}{2} \sum_i^n \sum_j^n \, _f z_i \, _f z_j \, s_{i,j} \quad .$$

Given that both $_f DV$ and $_f GDV$ are expressed in units of squared distance, it will assist our thinking in practical applications to take the square roots of both quantities as basic measures of overall distribution dispersion. Then, the measures $_f DV^{\frac{1}{2}}$ and $_f GDV^{\frac{1}{2}}$ will be expressed directly in units of geographic distance (miles, kilometers). However, names assigned to these measures differ among authors. Bachi (1957) and Duncan, Cuzzort, and Duncan (1961), following Bachi, refer to $_f DV^{\frac{1}{2}}$ as the <u>standard distance</u> of distribution dispersion and to $_f GDV^{\frac{1}{2}}$ as the <u>mean quadratic distance</u>. We prefer the terminology given by Neft (1966), however, and in keeping with our nomenclature for $_f DV$ and $_f GDV$, will refer to the measures $_f DV^{\frac{1}{2}}$ and $_f GDV^{\frac{1}{2}}$ respectively as the <u>standard distance deviation</u> and the <u>generalized standard distance deviation</u> of an areal distribution.

It should be noted at this point, however, that our derivations and expressions for both $_f DV$ and $_f GDV$ differ from those of Bachi and

Neft in a basic manner. Both Bachi and Neft, following standard procedures for computing the variance of grouped data, neglect the contribution to distance variance associated with intra-tract residual variances. Thus, the numerical consistency of their measures over different sampling frames would seem to depend strongly on the assumption that all areal units are small relative to the size of the urban area and, thus, potentially quite numerous. Bachi appears to acknowledge this condition in stating:

> Other things being equal, that frame should be preferred which . . . renders minimal the aggregate "within zone" squared distance and which renders maximal the aggregate weighted squared distance between the centers of the zones and the general center. (Bachi, 1957)

The methods that we propose here, however, take full account of the contributions to distance variance made by point distributions within tracts. In essence, the methods proposed here are directly analogous to procedures employed in physics for determination of moments of inertia for irregular shapes. These procedures are based on the well-known parallel-axis theorem of mechanics concerning the additivity of component second moments. By analogy with such procedures, we have chosen the above course in defining mathematically the distance variance of areal distributions in an effort to obtain greater consistency of our computations of ${}_{f}DV$ and ${}_{f}GDV$ over different spatial sampling frames.

E. Some Preliminary Measures of Spatial Association Between and Within Areal Distributions

Using the same concepts employed above in our presentation of general measures of areal distribution dispersion, we may define a

general measure of the spatial dissociation between two distributions in the following manner. Let f and g be two areal distributions represented respectively by vectors ${}_fZ$ and ${}_gZ$ of n elements each. Again, the elements of both ${}_fZ$ and ${}_gZ$ will be discrete probabilities proportional to aggregate data values recorded for each of the n areal units of a common spatial sampling frame.

Then we may define the <u>generalized squared distance of interaction</u> between the two distributions f and g as

$$\text{(A.22)} \qquad {}_{f,g}GDI^2 = \sum_i^n \sum_j^n {}_fz_i \; {}_gz_j \; s_{i,j}$$

where again the elements $s_{i,j}$ represent expected squared distances separating points paired randomly within and between tracts.

Now with simple but lengthy algebraic manipulation, it can be demonstrated that

$$\text{(A.23)} \qquad {}_{f,g}GDI^2 = ({}_f\bar{M}x - {}_g\bar{M}x)^2 + ({}_f\bar{M}y - {}_g\bar{M}y)^2 + {}_fDV + {}_gDV \quad ,$$

where ${}_f\bar{M}x$, ${}_f\bar{M}y$ and ${}_g\bar{M}x$, ${}_g\bar{M}y$ are the coordinates of the centroids of the two distributions. Here, notice the similarity between our expression for ${}_{f,g}GDI^2$ and our formulation of the expected squared distance between points of different tracts, $E(D^2_{i,j}) = s_{i,j}$, as defined by (3.12), (A.13), and (A.14). In both cases, our mean squared distance measure may be considered as consisting of three distinct components: (1) the mean squared distance from a randomly selected point of one distribution (tract) to the centroid of that distribution (tract), (2) the squared distance from the centroid of the one distribution (tract) to the centroid of the other, and (3) the mean squared distance from the centroid

of the other distribution (tract) to some other point randomly selected within it. Note also that where the distributions f and g are one and the same, then ${}_{f,g}GDI^2 = {}_{f}GDV = {}_{g}GDV$.

The above conditions hold only because, in the formulation of both ${}_{f}GDV$ and ${}_{f,g}GDI^2$, we assume complete spatial independence within the pairing of points within and between distributions. In other words, the present measures assume that the pairing of points within and between distributions occurs in a manner that in no way depends on spatial proximity relationships existing between distribution elements. The probabilistic weighting of mean squared distance components is determined solely in terms of the cross-product elements of the probability vectors ${}_{f}Z$ and ${}_{g}Z$ which, taken by themselves, are completely aspatial. Seeking more appropriate measures of spatial association between areal distributions, in the next section we will explore an alternative measure of mean squared distribution distance where spatial proximity relationships between distribution elements determine in part the probabilistic weighting of mean squared distance components.

F. A Spatial Interaction Approach to Measurement of Distribution Distance

Seeking a more informative measure of spatial association between areal distributions, by analogy with the intraurban trip distribution models discussed before, let us examine a specific spatial interaction models of the form:

$$(A.24) \qquad {}_{f,g}MDI^2 = \sum_{i}^{n} \sum_{j}^{n} {}_{f,g}q_{i,j} \; s_{i,j} \quad .$$

Here, ${}_{f,g}MDI^2$ denotes the mean squared distance of interaction between two distributions f and g, $s_{i,j}$ represents as before the expected squared distance between points paired between the i-th and j-th tracts, and ${}_{f,g}q_{i,j}$ denotes a probabilistic weighting of $s_{i,j}$ determined in part by the value of $s_{i,j}$ itself. Specifically, we will require that the matrix ${}_{f,g}Q$ (n x n) be a joint probability distribution with row marginals ${}_f z_i$, i = 1,...,n and column marginals ${}_g z_j$, j = 1,...,n where, again, ${}_f Z$ and ${}_g Z$ represent discrete probability vectors characterizing distributions of the aggregate variables associated with f and g over the n tracts comprising the spatial sampling frame.

Now let ${}_{f,g}\Pi$ denote the set of all ${}_{f,g}Q$ joint probability matrices having row marginals ${}_f Z$ and column marginals ${}_g Z$. Note then that any ${}_{f,g}Q \varepsilon {}_{f,g}\Pi$ may be considered as determining a probabilistic pairing of points between the areal distributions f and g and thus an inter-distribution pairing of points across all tracts as well.

One possible ${}_{f,g}Q$ matrix occurs, of course, where ${}_{f,g}q_{i,j} = {}_f z_i \, {}_g z_j$ for all i,j = 1,...,n. In this instance, our measure of ${}_{f,g}MDI^2$ is identically the same as our measure of ${}_{f,g}GDI^2$ defined in the preceding section. This represents the case again where complete independence exists within the pairing of points between the distributions f and g.

In general, however, it would seem desirable that our measure of ${}_{f,g}MDI^2$ be a function of a ${}_{f,g}Q$ joint probability distribution exhibiting some degree of stochastic interdependence or constraint attributable to whatever spatial interdependence, association, or congruence that may exist between the two areal distributions f and g. In other words, we wish our ${}_{f,g}Q$ matrix, already constrained to be a joint probability distribution with marginals ${}_f Z$ and ${}_g Z$, additionally to be determined as

a function of spatial proximity relationships existing between the elements of f and g. Just how this should be done represents a key issue of our thesis.

Now suppose, by analogy, we appropriate directly the mathematical concepts of the entropy-maximization model of trip distribution in an attempt to formulate an appropriate ${}_{f,g}Q$ matrix. Our model would then be:

$$\text{(A.25)} \qquad \max \; - \sum_{i}^{n} \sum_{j}^{n} {}_{f,g}q_{i,j} \log({}_{f,g}q_{i,j})$$

subject to the constraints,

$$\text{(A.26)} \qquad \sum_{i}^{n} {}_{f,g}q_{i,j} = {}_{g}z_{j} \qquad j = 1,\ldots,n \quad ,$$

$$\text{(A.27)} \qquad \sum_{j}^{n} {}_{f,g}q_{i,j} = {}_{f}z_{i} \qquad i = 1,\ldots,n \quad ,$$

$$\text{(A.28)} \qquad {}_{f,g}q_{i,j} \geq 0 \qquad i,j = 1,\ldots,n \quad ,$$

and the additional constraint,

$$\text{(A.29)} \qquad \sum_{i}^{n} \sum_{j}^{n} {}_{f,g}q_{i,j}\, s_{i,j} = {}_{f,g}MDI^{2} \quad .$$

It should be immediately obvious that such a model is inappropriate for our present task, since the very same variable that we wish to ultimately determine, ${}_{f,g}MDI^{2}$, appears in the constraint (A.29) as a numerical constant assumed to be known a priori.

In order to make several points, however, let us pursue further the investigation of this entropy-maximization approach to our problem. As is well understood, the solution to this particular model (Wilson,

1970; Potts and Oliver, 1972) is given by

(A.30) $$ {}_{f,g}q_{i,j} = {}_f u_i \, {}_f z_i \, {}_g u_j \, {}_g z_j \exp(-\beta s_{i,j}) \qquad i,j = 1,\ldots,n $$

where the vectors ${}_f U$ and ${}_g U$ are determined by iterative solution of the equations

(A.31) $$ {}_f u_i = \Big[\sum_j^n {}_g u_j \, {}_g z_j \exp(-\beta s_{i,j})\Big]^{-1} \qquad i = 1,\ldots,n $$

(A.32) $$ {}_g u_j = \Big[\sum_i^n {}_f u_i \, {}_f z_i \exp(-\beta s_{i,j})\Big]^{-1} \qquad j = 1,\ldots,n $$

and where β is the Lagrange multiplier associated with constraint (A.29).

Now from trip distribution theory, we know that there exists a one-to-one mapping between all real values of β and all feasible values of ${}_{f,g}MDI^2$. Further, we know that as β approaches $+\infty$, the associated value of ${}_{f,g}MDI^2$ approaches its minimal feasible value. (A. W. Evans, 1971; S. P. Evans, 1973) This is the minimal value of ${}_{f,g}MDI^2$ that would be obtained if we chose to solve the Hitchcock or transportation minimization problem uniquely determined by equations (A.24), (A.26), (A.27), and (A.28). (Dantzig, 1963; Dorfman et al., 1958) Thus, one possible way out of our dilemma concerning a choice for β would be simply to assume theoretically a β equal to $+\infty$ and solve for the unique minimal ${}_{f,g}MDI^2$,

(A.33) $$ {}_{f,g}LDI^2 = \min_{{}_{f,g}Q \in {}_{f,g}\Pi} \sum_i^n \sum_j^n {}_{f,g}q_{i,j} \, s_{i,j} \quad . $$

Brandon's work provides an efficient computer program of solving such problems in the context of pattern analysis. (Brandon, 1979)

This measure of minimal or least mean squared distance of interaction between distributions has some interesting properties. Elsewhere (Ray, 1974), we have demonstrated its applicability to the solution of certain pattern recognition problems. Among other desirable properties, it has the advantage that it may be minimized, not only over all ${}_{f,g}Q \varepsilon {}_{f,g}\Pi$ but over all scale, translational, and rotational transformations of the geometry of one spatial pattern relative to the geometry of another as well.

It might appear that another logical solution to our problem concerning a choice of a specific value for β might be simply to set β=0. Here, however, $\exp(-\beta s_{i,j}) = 1$ for all $s_{i,j}$ and thus the ${}_{f,g}Q$ matrix obtained via (A.30), (A.31), and (A.32) will in no way depend on intertract squared distances. In fact, it can easily be shown that, for this case where β=0, the value of ${}_{f,g}MDI^2$ will be identically equal to the value of ${}_{f,g}GDI^2$ given by (A.23).

Thus, the entropy-maximization model of trip distribution, applied directly, seems to offer little toward the determination of a unique ${}_{f,g}Q$ matrix reflecting spatial proximity relationships between distribution elements. It leaves us with an arbitrary choice of a real value for β. Consequently, we must make an arbitrary selection of a single ${}_{f,g}Q$ matrix from an infinity of possible ${}_{f,g}Q$ matrices.

Throughout this discussion, we have assumed that all ${}_{f,g}q_{i,j}$'s should be proportional to proximity relationships between distribution elements and, hence, somehow inversely proportional to the $s_{i,j}$'s. By well known theory of the entropy-maximization model, this implies that any appropriate β must lie between 0 and $+\infty$. At β=0,

${}_{f,g}MDI^2$ reverts to ${}_{f,g}GDI^2$. At $\beta=+\infty$, ${}_{f,g}MDI^2$ becomes ${}_{f,g}LDI^2$, a value that must be obtained by solution of a transportation programming problem. Adopting the transportation programming solution, we know that only a small number of the ${}_{f,g}q_{i,j}$'s will be non-zero, i.e., a number on the order of n+n-1 if we assume all elements of ${}_fZ$ and ${}_gZ$ to be non-zero. Consequently, only a small number of proximity relationships contribute to the determination of ${}_{f,g}MDI^2$. Thus, while providing an extremal measure, this model seems overly specific with respect to the information at hand.

G. A Unique Measure of Spatial Association Within and Between Areal Distributions

In this section we shall develop a specific measure of distribution distance of the form given for ${}_{f,g}MDI^2$ where the matrix ${}_{f,g}Q$ is determined in a unique manner relative to all spatial proximity relationships existing between distribution elements. Retaining the same meanings as before for our notations f, g, ${}_fZ$, ${}_gZ$, ${}_{f,g}Q$, ${}_{f,g}\Pi$, and S, our model is derived as follows.

Note that our measure ${}_{f,g}MDI^2$ given by (A.24) may be considered simply as a weighted sum of squared distance components between all distribution elements paired between f and g. To demonstrate this condition clearly, let ${}_{f,g}r_{i,j} = {}_{f,g}q_{i,j}\ s_{i,j}$ for all i,j = 1,...,n. Then we may express (A.24) simply as

$${}_{f,g}MDI^2 = \sum_i^n \sum_j^n {}_{f,g}r_{i,j} \quad .$$

Thus, ${}_{f,g}MDI^2$ is simply the sum of all elements of the new matrix ${}_{f,g}R$ (n x n) and our problem is now to specify in an appropriate manner the elements of ${}_{f,g}R$.

Now, suppose we adopt the objective that the elements of ${}_{f,g}R$ should have values as evenly distributed as possible subject to the conditions imposed on ${}_{f,g}R$ given that ${}_{f,g}Q\varepsilon{}_{f,g}\Pi$. To formalize this objective mathematically, scale ${}_{f,g}R$ by the constant $k^2=(\Sigma_i^n \Sigma_j^n {}_{f,g}r_{i,j})^{-1}$ so that the resulting matrix ${}_{f,g}R'=[k^2 {}_{f,g}r_{i,j}]=[{}_{f,g}r'_{i,j}]$ may be considered as a joint probability distribution. Then our objective becomes to determine that matrix ${}_{f,g}R$ whose associated joint probability matrix ${}_{f,g}R'$ is maximally entropic subject to the constraint that ${}_{f,g}Q\varepsilon{}_{f,g}\Pi$. In information-theoretic terms, the interpretation of this objective is that we should select that ${}_{f,g}R$ representing a least biased estimate, i.e., that ${}_{f,g}R$ that is maximally noncommittal with regard to missing information. (Jaynes, 1957)

Now considering ${}_{f,g}R'$ as a joint probability matrix, let the vectors U and V denote respectively its row and column marginal probabilities such that

$$u_i = \sum_j^n {}_{f,g}r'_{i,j} \qquad i = 1,\ldots,n \quad ,$$

$$v_j = \sum_i^n {}_{f,g}r'_{i,j} \qquad j = 1,\ldots,n \quad .$$

Now necessarily $H({}_{f,g}R') \leq H(U) + H(V)$, and the upper bound of $H({}_{f,g}R')$ is obtained only if ${}_{f,g}R'$ has the form

$${}_{f,g}r'_{i,j} = u_i v_i \qquad i,j = 1,\ldots,n \quad .$$

Let us assume momentarily that $H({}_{f,g}R')$ does indeed attain its upper bound. Then, we must have

$$k^2 \; {}_{f,g}q_{i,j} \; s_{i,j} = u_i v_j \qquad i,j = 1,\ldots,n$$

and consequently

(A.35) $$ {}_{f,g}q_{i,j} = u_i v_j k^{-2} s_{i,j}^{-1} \qquad i,j = 1,\ldots,n. $$

Now let $u'_i = k^{-1}u_i$, $i=1,\ldots,n$ and $v'_j = k^{-1}v_j$, $j=1,\ldots,n$. Then (A.35) may be expressed

$$ {}_{f,g}q_{i,j} = u'_i \, v'_j \, s_{i,j}^{-1} \qquad i,j = 1,\ldots,n. $$

With reference to the constraint that ${}_{f,g}Q \varepsilon {}_{f,g}\Pi$, we have

$$ \sum_i^n {}_{f,g}q_{i,j} = {}_g z_j \qquad j = 1,\ldots,n \quad , $$

$$ \sum_i^n u'_i v'_j s_{i,j}^{-1} = {}_g z_j \qquad j = 1,\ldots,n \quad , $$

$$ v'_j \sum_i^n u'_i s_{i,j}^{-1} = {}_g z_j \qquad j = 1,\ldots,n \quad , $$

and thus,

(A.36) $$ v'_j = {}_g z_j \left(\sum_i^n u'_i s_{i,j}^{-1}\right)^{-1} \qquad j = 1,\ldots,n. $$

By an identical manner, it may be shown that

(A.37) $$ u'_i = {}_f z_i \left(\sum_j^n v'_j s_{i,j}^{-1}\right)^{-1} \qquad i = 1,\ldots,n. $$

Now (A.36) and (A.37) represent a set of 2n equations which, in a manner identical to the determination of "balancing factors" within trip distribution modeling, may be solved iteratively for the 2n unknowns of the vectors U' and V'. Solution may proceed in the following

manner. First, initialize the U' vector by setting $u'_i = 1$ for all $i = 1,\ldots,n$. Then with equations (A.36), determine a first approximation of V'. Use this V' within the equations (A.37) to determine a new U', return to equations (A.36), and so forth.

Such an iterative procedure will determine values for U' and V' that are unique up to a positive scalar multiple; that is, given that U' and V' satisfy (A.36) and (A.37), then $U''=cU'$ and $V''=\frac{1}{c}V'$ will also satisfy (A.36) and (A.37) where c is any positive constant. For our purpose here, we should periodically throughout the iterative solution of (A.36) and (A.37) re-scale U' and V' such that $\Sigma_i^n u'_i = \Sigma_j^n v'_j$. Then, at convergence, we may determine the constant k^{-2} of (4.1) from the condition that $\Sigma_i^n u'_i = k^{-1}\Sigma_i^n u_i = k^{-1}$, or alternatively from the condition $\Sigma_j^n v'_j = k^{-1}\Sigma_j^n v_j = k^{-1}$. These relationships between the vectors U, V, and U', V' via k^{-1} imply mathematical uniqueness for the values of U, V, and k^{-2}; hence, by substitution of these unique U, V, and k^{-2} into equation (A.35), the uniqueness of ${}_{f,g}Q$ itself is assured. Let us denote the unique ${}_{f,g}Q$ so derived as ${}_{f,g}Q^*$.

The fact that equation (A.35) has a solution satisfying all a priori conditions insures that the entropy function defined for ${}_{f,g}R'$, $H({}_{f,g}R') = -\Sigma_i^n \Sigma_j^n\, {}_{f,g}r'_{i,j} \log {}_{f,g}r'_{i,j}$, does indeed attain its upper bound, i.e., $H({}_{f,g}R') = H(U) + H(V)$. Furthermore, we have seen that this solution is unique. Thus, assuming only that ${}_{f,g}Q \epsilon\, {}_{f,g}\Pi$ and that, otherwise, all weighted component squared distances of interaction between distribution elements should be allocated as evenly as possible over all element pairs, i.e., their distribution should be maximally entropic, we have arrived at the distance measure

$$(A.38) \qquad {}_{f,g}EDI^2 = \sum_i^n \sum_j^n {}_{f,g}q^*_{i,j}\ s_{i,j} \quad .$$

We will refer to this measure of distribution distance as the entropic squared distance of interaction between two distributions f and g. Taking the square root of ${}_{f,g}EDI^2$, we have simply the entropic distance of interaction between two distributions, ${}_{f,g}EDI$.

The measure ${}_{f,g}EDI^2$ appears to be unique with respect to the following five properties desirable for any measure of distribution distance.

1. As a weighted sum of squared euclidean distances, ${}_{f,g}EDI^2$ is invariant with respect to all translations and rotations (orthogonal transformations) of frame coordinates. This condition follows from the translational invariance and the unique rotational invariance properties of euclidean distance (Beckenbach and Bellman, 1961) together with the fact that all weights themselves depend only upon their associated squared distance components and the fixed vectors ${}_fZ$ and ${}_gZ$.

2. The square root of ${}_{f,g}EDI^2$, ${}_{f,g}EDI$, is homogeneous with respect to scale transformations of frame coordinates. To illustrate, suppose frame coordinates are converted from miles to kilometers. Then ${}_{f,g}EDI$ in kilometers, re-computed using the new frame, would be simply the old ${}_{f,g}EDI$ in miles times the conversion factor 1.6. (Note that this property does not hold for the entropy-maximization model of trip distribution because of the reliance of the model on the functional $\exp(-\beta d_{i,j})$. If the $d_{i,j}$'s are re-scaled, then the parameter β must also be changed if the interzonal trip distribution matrix is to remain unaltered.)

3. As an estimator of areal association between two distributions

f and g, ${}_{f,g}EDI^2$ is numerically consistent with respect to the resolution of the spatial sampling frame. The smaller and more numerous the areal subdivisions, the more accurate the measure obtained. Where f and g are the same distribution, ${}_{f,g}EDI^2$ approaches zero as the number of areal subdivisions of the frame increases. At any intermediate level of frame resolution, where either f=g or f≠g, the value of ${}_{f,g}EDI^2$ depends only incidentally on the specific frame selected. Unlike traditional ecological correlation measures computed as a function of f and g data values coincident within individual tracts, ${}_{f,g}EDI^2$ is computed as a function of all data values associated within and between all tracts in a manner proportional to spatial proximity relationships existing among tracts.

4. As a weighted sum of squared distances between points of two x,y bivariate distributions f and g, the value of ${}_{f,g}EDI^2$ may be decomposed into a series of additive terms that includes measures of the x and y component variances of the coordinates of points within both f and g. Additionally, this series may be arranged to have terms expressing the x and y component covariances of the coordinates of point pairs spatially associated between f and g as a consequence of the probabilistic matching of points between distributions that is implied by ${}_{f,g}Q^*$. (Bachi, 1957) This decomposition property of ${}_{f,g}EDI^2$ results uniquely from its formulation as a sum of squared distances.

5. The measure ${}_{f,g}EDI^2$ is formulated in a least biased manner. As a weighted sum of squared distances between points of f and points of g, the distribution of all component weighted squared distances is made maximally entropic subject to the single constraint that the weighting occur as a joint probability function having marginals ${}_fZ$ and ${}_gZ$.

APPENDIX C

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. Structure of spatial associations, spatial efficiency index, and pattern distance measures and relationships were introduced as concepts for practical comparative analysis of urban spatial structures across U.S. cities.

Demography, Housing and Transportation

A DETAILED PROPOSAL ON: NEW IMPLICATIONS FOR TRANSPORTATION POLICY FROM DEMOGRAPHICS, HOUSING DEMAND AND METROPOLITAN GROWTH

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STUDY DESIGN REPORT

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1.0 PROBLEM STATEMENT

Demographics are basic to transportation, as they are to all social and economic concerns. Demographic variables affect transportation directly, as in the case of transit captive trip makers who are either too young or too old to drive their own automobiles. Indirect effects of demographics on transportation are also important, as in the case of household formation, and also the transformation of households by type, both of which are conditioned by birth rates two and three decades ago, and which affect residential patterns, which in turn largely determine future transportation needs and the feasibility of particular transportation systems. In short, the extent and type of needed transportation investment are strongly affected by major demographic shifts. Basic research is required which highlights the demographic shifts, interprets their effects, and draws out their transportation implications.

2.0 UNDERSTANDING THE PROBLEM

2.1 THE COMING-OF-AGE OF THE BABY BOOM

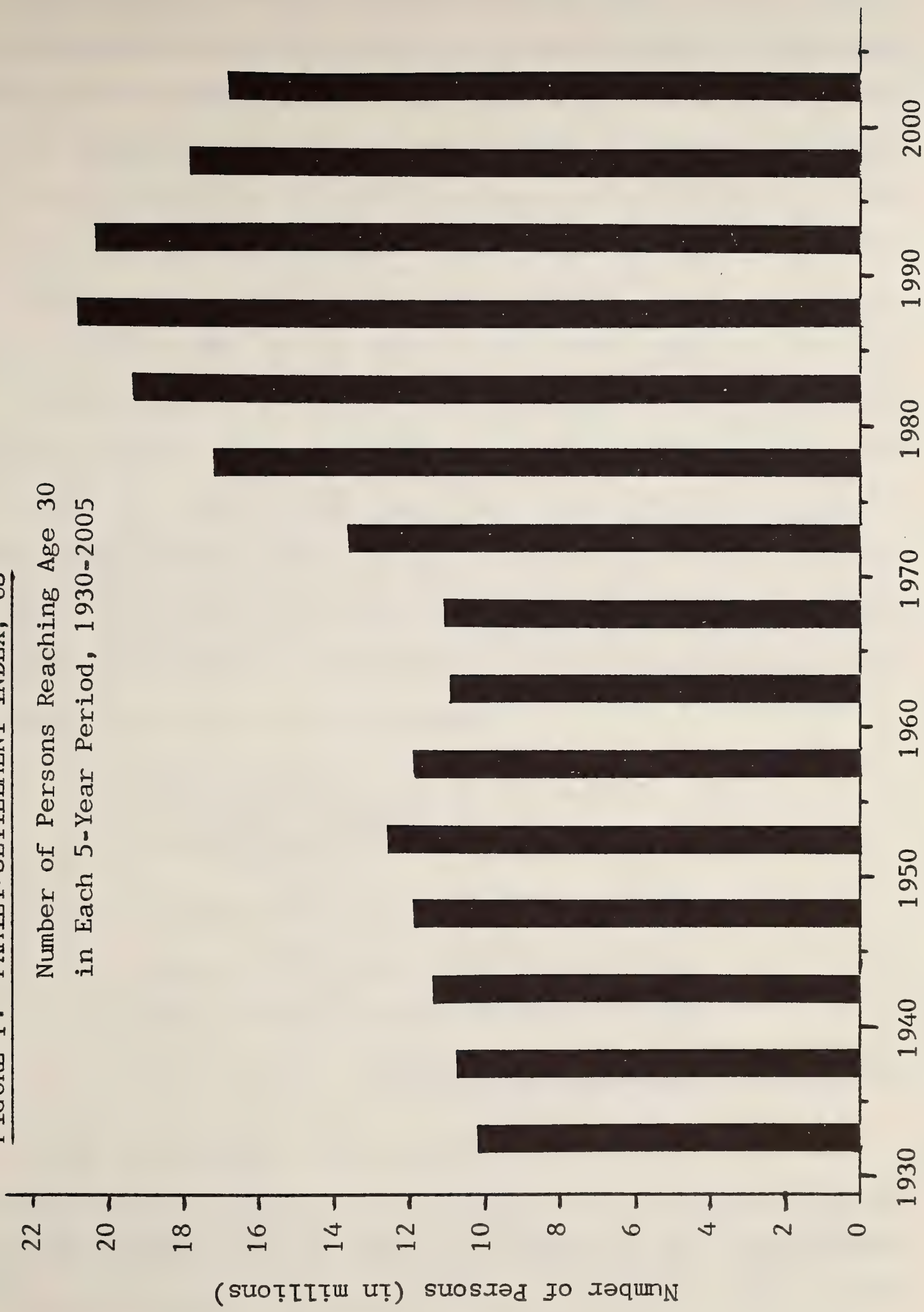
The coming of age of the post-war baby boom generation is one of the three or four major demographic events of this century, comparable in its impacts with the great rural-to-urban migration of the 19th and early 20th century, with the post-war suburbanization phenomenon, and with the large secular declines in fertility and mortality which have occurred since 1900.

The post-war baby-boom generation is easily the largest in our history. The tremendous burden which this generation put on the public school system in the 1950's is indicative of its capacity to force major and rapid changes in family residential patterns and associated infrastructure, as the people of this generation pass through what we may call the family settlement stage of life. Taking age 30 as the age of family settlement, the period of impact of the baby-boom generation (born 1947-1965) on family housing and residential patterns will be 1977-1995. About 21 million Americans will reach age 30 between 1985 and 1990, compared to 11 million in both 1960-65 and 1965-70 and to some 12 million in other recent five-year periods. (See Figure 1.)

The record levels of single-family housing construction and the rapid housing price increases which have occurred generally in the U.S. in the last two or three years (and which have been spectacular in certain regions) were predictable as

FIGURE 1: FAMILY-SETTLEMENT INDEX, US

Number of Persons Reaching Age 30
in Each 5-Year Period, 1930-2005



results of the impact of the leading edge of the baby-boom generation. In the three years which have elapsed since the leading edge of the baby-boom generation reached age 30, single-family housing starts have averaged 1,360,000 units/year (1977-1979), compared with an average of 990,000 units/year during the previous 10 years. In these same three years, the U.S. Commerce Department's price index for new single-family houses rose 46.9%, or 13.4% annually, while the consumer price index (CPI) of all goods and services was rising at 8.4% annually (see Table 1). Thus, single-family house price increases have outpaced general inflation by 5% annually in the past three years. By comparison, during the previous 10 years (1976 vs. 1966) single-family housing price increases outpaced inflation by only 1%: the housing price index rose 6.7% annually while the CPI rose 5.8% annually.

TABLE 1

Year	CPI	S-F House Price Index
1966	97.2	74.2
1976	170.5	142.0
1979	217.4	207.2

2.2 "NORMAL" METROPOLITAN DYNAMICS

The suburbanization phenomenon as it has existed since the end of World War II has resulted in an extremely characteristic stratification of the social geography in metropolitan areas. The most important characteristics are (a) a concentration of

young families with children in the suburban and exurban areas, (b) a concentration of young adults in selected urban core areas, and (c) a concentration of the elderly in most urban core areas.

This can be illustrated by the Eastern Massachusetts population. Figure 2A depicts the proportion of the Eastern Mass. population living in the post-war suburbs by age. It clearly shows the concentration of young parents and their children and the shortage of young adults (about age 20) in the suburbs. (The complement of this figure would obviously show the concentration of young adults in the cities.) While this type of geographic distribution has been roughly stable for at least two decades, the individuals involved are of course continuously growing older, which means that very high rates of intra-metropolitan age-specific migration are necessary to sustain this approximately stable* distribution. The key dynamics are:

(1) Young families move to the suburbs (or exurbs) to raise children.

(2) At about age 18, children leave their parental homes and gravitate to those urban cores which are centers for educational and entry-level training

---

*Note that what is stable is the relative concentration of different age groups; this is against a background of steady dispersion involving all age groups, even young adults and the elderly.

FIGURE 2a
SUBURBAN PARTION PROPORTIONS
BY YEAR OF AGE
FEMALES
BOSTON REGION

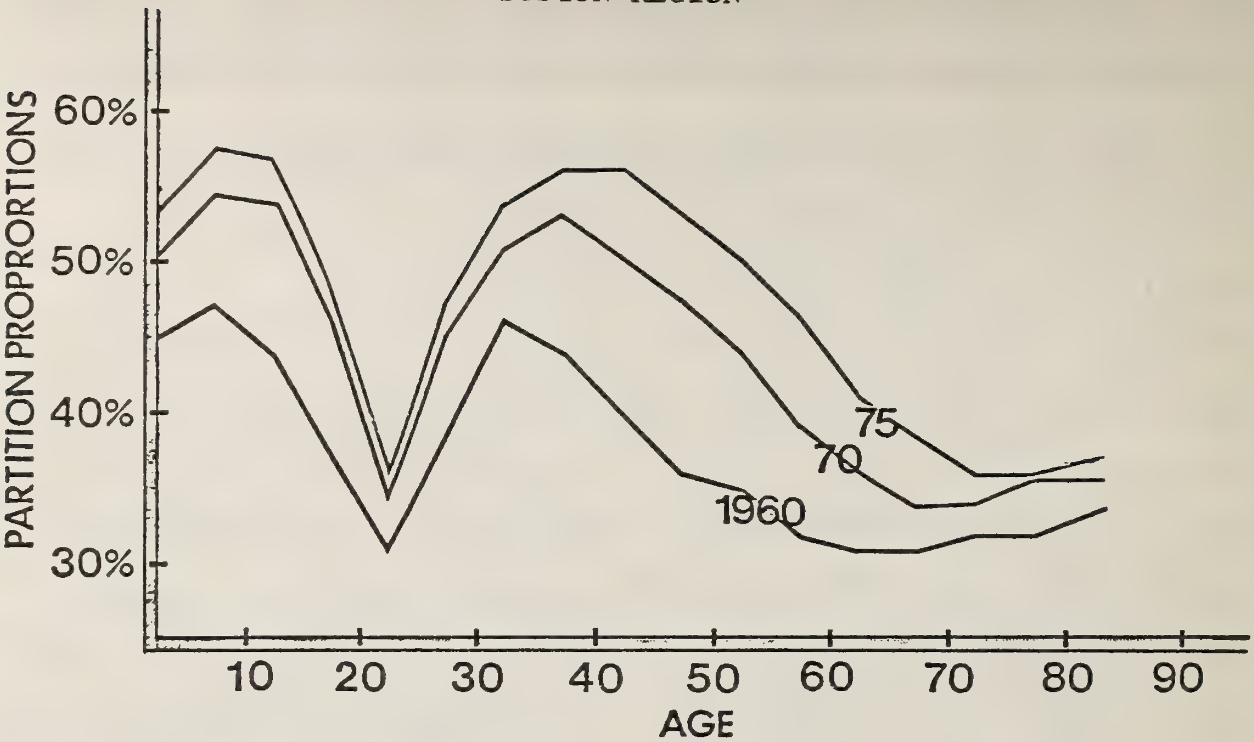
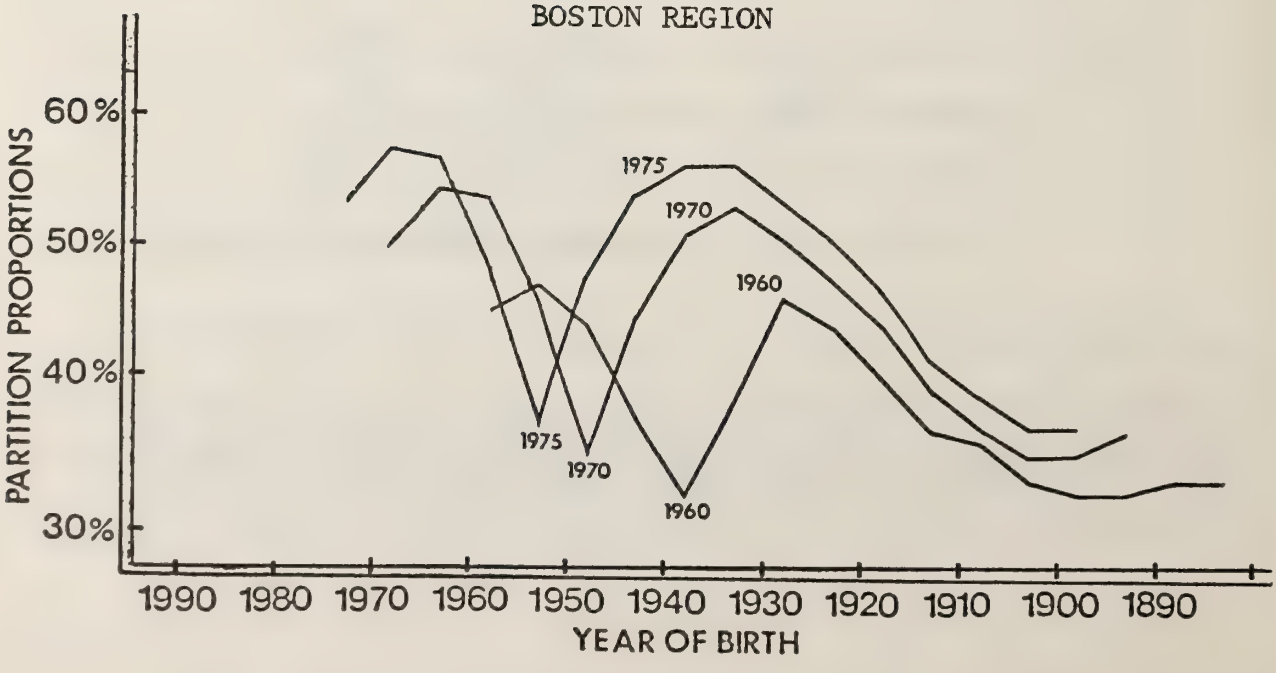


FIGURE 2b
SUBURBAN PARTITION PROPORTIONS
BY YEAR OF BIRTH
FEMALES
BOSTON REGION



(resulting in an exodus at age 18 from suburban areas).

(3) Middle-aged and older people tend to have low residential mobility regardless of location.

Figure 2A demonstrates that the migration "triggers" are strongly age-determined for persons below about age 35. On the other hand, Figure 2B, which is based on year of birth rather than on age, shows that the increasing proportion of middle-aged and elderly people in the suburbs results mainly from the non-moving of these individuals (many of whom had arrived as young parents in the 1950s and 1960s) rather than from an influx of people in this age range.

From a policy-planning perspective, the salient implication of these dynamics is that they are now such a familiar part of American metropolitan life that most people intuitively regard them as "normal" and incorporate them into their personal life-course expectations.

2.3 FUTURE METROPOLITAN DYNAMICS: A QUESTION MARK

Clearly, the large size of the baby-boom generation means that a continuation of the "normal" dynamics of the past would lead to sharp increases in suburban and/or exurban population and households in the next two decades, as the baby-boom generation reaches the family-settlement stage in life. The question is, will the baby boom follow the footsteps of their parents?

Survey research has continually identified urban fringe areas as the most desired residential location. Very importantly, such research has consistently demonstrated that people have a "homing" tendency, in that individuals from every type of community tend to have an above-average preference for the type of community in which they grew up. This finding would suggest that the baby-boom generation -- the first generation to be raised primarily in the suburbs -- will have an even stronger preference for this type of community than that which their parents actually demonstrated 25 years ago by their location decisions.

Such preferences, however, do nothing to assure that the door to the suburbs will be open when and if the baby-boom generation knocks on it. A number of barriers to growth in the suburbs have been identified in the literature and addressed by various government agencies and builders' associations, including (1) "no-growth" sentiment in large portions of U.S. metropolitan areas outside the core areas (note that "no-growth" sentiment is often covertly expressed in terms of unduly strict or cumbersome environmental or health requirements or various measures intended to increase costs, such as requirements for 45-foot wide streets, large lots, granite curbing, etc.), (2) moderate but genuine land shortages in many post-war suburbs (the areas which experienced large growth spurts between 1950 and, say, 1965, and in which only a few scattered large parcels are left, which are now being held by families or speculators), and (3) the low accessibility and high transportation costs associated with the remote areas,

where buildable land is still available in abundance, and (4) in some cases deliberate government policy to concentrate future metropolitan growth. This is not to say that there is not also substantial sentiment in the closer-in areas (those which were already built up before the war) against the kind of growth that would be possible here -- viz., conversion to higher densities. Rather, our focus now is on the suburban areas, and particularly on the post-war suburbs, because both the past trends in family-settlement decisions and the preference literature indicate that these are the most desirable locations for family settlement.

A key factor in the political strength of the suburban "no-growth" sentiment is that the suburbs have an unusually high concentration of middle-aged people, who are therefore at the peak of their earning power. These are basically the people who created the suburbs as we know them today, and they are now the controlling class. It is not difficult to see the self-interest of this group in "preserving" what they created, and it is clear that their power for this purpose is very considerable. Ironically, they are basically the parents of the baby-boom generation.

The baby-boom generation is so large that - absent growth barriers - its needs can easily cause record housing growth in <u>both</u> cities and suburban areas of our metropolitan areas. For example, even if the 30 largest cities in Massachusetts increase their housing stock at nearly twice the rate in the 1950s and 1960s (a target considered ambitious by state and

local officials), these cities could accommodate only 30% of all new housing in the coming decade. Therefore the balance of the state will still have to accommodate 70% of all new housing in the coming decade and grow some 25% faster than ever before - even faster than in the 1950s and 1960s, the heyday of post-war suburbanization! This prospect often provokes dismay and disbelief from local officials. The obstacles to sharply increased housing growth in either cities or suburbs are formidable indeed, and any shortfall in one sector will obviously entail still greater growth pressure in the other sector.

Clearly something has to give. The questions of what and where cannot be answered by reference to historical precedents, for there are none. Nothing like the baby boom has ever happened before.

In short, the unresolved - and probably unresolvable - question of where the baby-boom generation will settle poses an enormous uncertainty for devising transportation policies to match the development patterns of the next two decades. These policies must reflect changing demand conditions, of which the baby boom is a major determinant, while changing transportation supply conditions, such as gasoline price increases, further constrict the range of options available as policy choices.

2.4 THE BABY BOOM AND THE FAMILY HOUSING CRUNCH

An important factor in forecasting metropolitan growth patterns is the prospect that there will be a major housing "crunch" in the 1980s -- in terms of affordability and availability -- and that family housing will be very severely affected. Although it is not easy to forecast how people will behave when the driving forces on them make quantum leaps, some kind of forthcoming crunch is plainly indicated by the collision course between (1) a further rapid increase in the total number of households, including especially young families with children, which seems to be an inevitable consequence of the current high rates of household headship and the maturation of the baby-boom generation, and (2) the formidable array of barriers to rapid housing growth in nearly every sector of major metropolitan areas of the U.S.

A key point in this argument is the assumption that headship rates are not very flexible in terms of downward movement under economic pressure -- although the spectacular headship gains during this century (particularly for young adults and the elderly) were presumably a response to increases in real income. The principal evidence supporting such a "rachet-effect" assumption is that even the Great Depression failed to lower headship rates significantly. The rates for even the younger, more volatile age groups were nearly stable. The proportion married, which is closely associated with headship, was also nearly stable during the Depression. (See Tables 2a and 2b) The extreme tenacity thus demonstrated by Americans in holding on to their

Table 2

Effect of Great Depression on Marriage and Household Headship, Selected Age Groups

Table 2a

Proportion Married

	1930	1940	Change	
Males				
Age 20-24	28.1%	27.4%	-0.7%	+0.6%
25-29	61.3	62.7	+1.4	
30-34	76.0	77.2	+1.2	
Females				
Age 20-24	51.6%	51.3%	-0.3%	-0.5%
25-29	74.3	74.1	-0.2	
30-34	81.5	80.4	-1.1	

Table 2b

Proportion Who Are Household Heads

	1930	1940	Change
Males*			
Age 25-34	62.1%	61.8%	-0.3%
35-44	80.1	79.2	-0.9
Females*			
Age 15 & over	8.6%	10.6%	+2.0%

*Household headship data in 1930 not available by age for females and available only by 10-year age groups for males.

housing independence suggests that it would take a very extraordinary economic dislocation to significantly alter headship behavior.* Therefore, it would be unrealistic to expect the housing crunch to be alleviated or averted by a decrease in headship rates ("doubling up"). In short, sharp increases in the number of households are virtually an inevitable consequence of the maturation of the baby-boom generation.

Another key point in this argument is the assumption that the proportion of the baby-boom generation who marry and have children will not be greatly different from in previous generations, and thus their housing demands will be felt mainly in the family housing market. Seemingly counter-indicative changes in household behavior -- such as lower fertility, delayed childbearing, delayed marriage, and higher divorce rates -- have received considerable media and scholarly attention in recent years. However, the fact which is often missed is that what has not changed is far more important than what has changed: the vast majority of Americans still marry and have children. Even if one extrapolates some of the apparent recent trends (a dubious

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*It could be argued that the nature and extent of headship increases in recent decades has introduced a strong luxury aspect into housing consumption, which might make headship much more elastic than it was 50 years ago, when housing was still consumed primarily as a basic necessity. On the other hand, the general social-welfare philosophy in the American body politic nowadays protects individuals against sudden loss of economic status (both through such "automatic stabilizers" as unemployment compensation and ad hoc Congressional responses to specific crises) and would thus buttress housing independence in even a severe recession.

procedure) it is evident from the statistics that marriage and family-rearing are here to stay -- at least for any useful planning horizon. In particular, declines in fertility and in childbearing expectations signal primarily the demise of large families (4 or more children); no data now exist to support a prediction of substantially increased childlessness.

In short, the evidence is strong that most of the baby-boom generation will marry and have children, so there is every reason to expect the immense housing needs of this giant generation to be felt in the family housing market in the coming years.

Moreover, it should be pointed out that -- but for the continuing trend toward later marriage and childbearing - family housing demand would have been increasing much faster in recent years than it in fact did. The fact that these key ages have been increasing at the rate of about one year per decade means that in the past 10 years only "9 years' worth" of the baby boom have married and had children. That is, the impact of the baby boom on the family housing market has been attenuated by a factor of about 0%. Alarmingly, the stability of this attenuation factor depends on maintaining the current trend toward increasingly later marriage and childbearing; when and if the ages of marriage and childbearing ever stabilize, then the attenuation effect will disappear, resulting in an even larger impact on the family housing market than is implied by Figure 1 above. Thus, while the total number of people who will be reaching "family settlement age" (taken as age 30 or a similar age) is rather precisely known

and will be rising steadily until the late 1980s, the number who will also have family housing needs will not keep pace (proportionately) with the rising numbers of people unless the trends toward increasingly later marriage and childbirth continue at the same rate. The number with family housing needs will rise significantly faster or slower, respectively, than the number reaching age 30 if this trend either abates or accelerates.

2.5 RESOLVING THE HOUSING CRUNCH

In short, it seems all but certain that a tremendous "crunch" in family housing will occur in the next few years as a result of the great surge in demand from the baby-boom generation coupled with no-growth attitudes and other barriers to growth. The way this "crunch" is resolved will have far-reaching impacts on the ultimate settlement patterns of the baby-boom generation and on metropolitan growth pattern dynamics generally. The initial stages of this "crunch" are already visible, in the increases in prices and construction rate. Less visible is a rapidly increasing backlog of unmet demand, resulting from the price increases and restricted location choices, which are forcing the middle-income segment of the baby-boom cohorts to delay crossing the threshold from renting to home ownership, and which are precluding home ownership to an even larger fraction of the low-income segment than usual.

Other things being equal, this backlog would grow steadily until at least the late 1980s (when the number of persons reaching family settlement age will peak). As a practical matter, the pressure building up from this backlog will probably be vented within the next, say, five years by any of several accommodation mechanisms, including, for example:

(1) Forced changes in preferences for residential location and housing type in response to market pressures. For example, more young families would accept high-density urban living as a way of life, permanently readjusting their housing and location expectations accordingly. The probability of such a transition of expectations will be increased if the federal and state governments either take a laissez faire stance -- i.e., allow the combination of local no-growth sentiment and high demand to simply take its course -- or implement conscious policies designed to encourage and facilitate such a transition.

(2) Massive intervention by the federal and/or state governments designed to assure young families of the baby-boom generation a range of choices similar to that open to recent generations. Many, if not most,

> forms of such large-scale government intervention would have very dispersive implications.

The political stakes in any severe housing crunch will obviously be very high; few public officials will counsel compromising on the "American Dream." This suggests that some form of large-scale government intervention at a supra-local level is likely.

An important question for policy makers is whether to consolidate the "bad news" from several different but related sectors (including transportation) into one large crisis. This will ease acceptability of individual crisis-intervention measures such as rationing, override of local zoning controls by state and federal interests and taxation schemes to reallocate resources. If this approach is taken, then transportation-policy prescriptions such as banning auto travel in central areas or during selected time periods, or provision of free public transportation service, should be combined with other stringent measures such as rent controls, forbidding evictions caused by condominium conversions, and requiring suburbs to increase allowable densities. Such combined policy "packages" might also include tax changes, subsidies to disadvantaged groups, etc., and would be proclaimed with great "fanfare" and ceremony. To continue to put the burden of adjustment on one or two sectors, e.g., housing or transportation, will be 1) unfair and 2) ineffective.

3.0 TRANSPORTATION IMPLICATIONS

A population cohort is generally longer lived than a given transportation investment. Examining and comparing the behavior of different cohorts, with particular attention to the degree of similarity and the range of differences among the cohorts at different points in this century, is instructive for national transportation policy analysis. Tracing through the implications of expected cohort behavior as they pass into the 1980's and 1990's will serve to highlight the major needs in transportation service provision. While the most direct implications can be drawn for personal transportation, it will also be possible to envision impacts on the movement of goods. Relationships between population and economic activity levels and trip generation have been clearly established. Use of this well-documented information in concert with demographic analysis will help establish what the shifts in transportation requirements in the next two decades are likely to be.

The following major sets of relationships summarize the kind of policy implications that can be drawn from demographic analysis:

Relationship #1

Total households are growing at a faster rate than population.

Transportation Policy Implication: Depending on where the increasing housing demand is being met (especially city or suburb), market potentials for public transportation will

be affected. Key intermediate variables are the housing market and state and local growth policies. Both must be examined and interpreted in terms of specific modal and submodal transportation service levels required.

Types of public transportation services most appropriate for various population densities have been studied and reported.*

Based on projected population densities from our allocation of population and households, it will be possible to identify the type of public transportation service best suited to each particular geographic sector in each of the three metropolitan areas. These services can be compared with services now provided in these sectors to determine if any changes should be considered. Types of services to be separately identified are local bus, express bus, and rail. The analysis will show whether the dispersion scenarios require different types of public transportation systems from those that now exist.

Relationship #2

Household growth will be concentrated in the 30-39 age group for two decades.

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*See, for example, "Optimizing Urban Mass Transit Systems: A General Model," Alvin Black, Transportation Systems Analysis, Transportation Research Record 677, 1978, and Bus Rapid Transit Options for Densely Populated Areas, UMTA, February 1977.

Transportation Policy Implication: This "growth spurt" in young family households will be a once-in-a-century phenomenon caused by the post-war "baby boom" (1947-1965). As the baby-boom generation enters this age range, which is traditionally the time for family settlement, it will establish transportation habits and needs likely to persist, just as the automobile-oriented habits and needs of their parents.

> From now until the end of the 1980's an unprecedented opportunity exists to influence modal choices by the type of transportation service and cost levels established. However, this opportunity may be lost as early as the mid-1980's if the looming crisis in family housing stampedes the federal and state governments into ill-conceived programs having adverse implications for transportation investments and other growth-policy considerations.

Research has shown that transit ridership tends to be higher in areas where transit services were available at the time when the area was developing -- even given lower residential densities.* However, given policies that essentially

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*Kain, John F., Gary R. Fauth, and Jeffrey Zax, Forecasting Auto Ownership and Mode Choice for U.S. Metropolitan Areas. Research Report R77-4, Harvard University Department of City and Regional Planning, December 1977.

force residential growth to occur in areas very difficult to service with public transportation (e.g., the exurbs), as represented in our high dispersion scenario, there will be no opportunity to encourage a "transit habit" among these dispersed residents. This means that policies favoring our "high dispersion" scenarios would forfeit the opportunity to orient the baby-boom generation towards public transportation.

Relationship #3

Middle-aged and elderly people (age 55 and over) have low rates of residential mobility, and these rates have further declined since 1970 (despite popular notions that "empty nesters" and elderly are increasingly moving into elderly housing and migrating to retirement/recreation spas).

Transportation Policy Implications: Because of falling birth rates and longer life expectancy, the elderly are becoming a proportionately larger segment of our society. Their low and declining rate of residential mobility has a profound effect on the housing market. It also creates pressures to establish or expand "senior citizen" transportation services. These, in particular, tend to have rapidly increasing deficits. These deficits may be seen as a subsidy enabling the elderly to continue their "overconsumption" of housing.

Growth in elderly population tightens the supply of housing suitable for young families at the very time when the demand for this type of housing is rising to unprecedented

levels due to the baby boom and at a time when "no-growth" attitudes are also tightening the supply, especially in many of the areas considered most suitable for families with children. Young families, caught in this pincer movement, may increasingly be forced into extreme choices of location and housing type...inner-city multi-family high-density living, or exurban very-low-density living. Again, the housing market and attitudes toward growth are the key intervening variables. Demands for transportation will be markedly different depending on the extent to which these two extreme choices prevail among new and relocating households.

Relationship #4

Population migration to exurban and rural areas and smaller metropolitan areas, while increasingly observable, is not of sufficient magnitude in relation to the population of large metropolitan areas to alleviate housing and growth pressure in the large areas (although the migration is of sufficient magnitude to have very noticeable impacts on the low-population areas which are receiving it).

Transportation Policy Implication: Existing transportation systems in our larger metropolitan areas will require maintenance and improvement, while new ones will have to be built in growing, smaller metropolitan areas to accommodate the decentralization. Increasing also, in rural areas adjacent to metropolitan areas, there will be demands to extend

transit lines or expand or establish demand responsive systems. It will be more economic to serve these people in closer-in areas.

In summary, the no-growth syndrome in suburban areas is creating great uncertainty for policy makers. It is also responsible, in part, for the decreasing equity in socio-economic groups. Some of the choices facing middle- and lower-income groups severely strain household budgets. Increasing housing costs cause people to re-examine the broad array of expenses they face. Transportation is a threshold type cost. When one depends primarily on the private automobile, a certain array of fixed costs are required. A different cost spectrum faces those who rely, for some or all travel, on public transportation. Essentially, public transportation costs tend to be less lumpy. That is, large expenditures for acquiring and maintaining a vehicle are not required.

This condition, added to the rapidly increasing costs of operating automobiles, means more people potentially will be users of public transportation. However, population densities must be high enough to justify investment in public transportation. Furthermore, public transportation routes must provide convenient links between residential and employment areas. If continued, and even accelerated, dispersion of residential areas results from restrictive growth policies, public transportation potentials will not be realized. It is imperative, then, that the U.S. Department of Transportation join with those advocating that future residential growth be reconcentrated in existing urban and suburban areas.

4.0 PROPOSED TECHNICAL APPROACH AND TASKS

It is proposed that the effects of the expected rapid expansion of family housing demand in the United States in the coming decade be explored by means of case studies of the future metropolitan dynamics in three specific metropolitan areas. A research program is outlined below to identify the key demographic variables in the three regions and a range of possible economic and non-economic factors which influence intra-regional population distribution, including alternative housing and transportation policies; and to then infer future distribution of the population (by age and household characteristics) over the sectors of the metropolitan areas under various assumptions. Transportation system needs and the effectiveness of various transportation investment strategies under different assumptions will be explored. The findings of this research will be interpreted for their implications for other regions.

Project work has been divided into three major phases. They are:

- Phase I: Reconnaissance and Data Collection on the Three Metropolitan Areas
- Phase II: Analysis and Modeling of Growth and Dispersion and Household Behavior
- Phase III: Analysis of Transportation and Related Housing and Growth-Policy Implications

Phases II and III are to be done simultaneously, to some extent, because the analysis of policies will affect how the growth model and dispersion scenarios are defined and applied in detail.

Fifteen tasks are defined to carry out the work of the project. Each task applies to all three metropolitan areas to be studied, except for the geographically non-specific tasks. Preliminary work in selecting these areas has already been done. Considerable material has been collected and reviewed in selecting the Boston, Seattle, and Houston metropolitan areas. Selection criteria are as follows:

- Population size (over one million).
- Range of auto/transit dependence.
- Regional coverage (Far West, Sunbelt, Northeast/Midwest industrial belt).
- Population growth range (from high to low).
- Good current data availability (recent studies and data updates on housing, transportation, and land use, including small-area data).
- Recent consideration of regional development patterns (e.g., existence of recently-developed and applied transportation/land use model or a growth policy exercise).

The Boston, Houston, Seattle metropolitan areas were judged to best meet this combination of criteria. Boston is essentially a stable transit-oriented area with substantial net out-migration of population, while Houston is an auto-oriented area with substantial net in-migration of population, and Seattle is intermediate in both respects. The development patterns of Boston and Houston are roughly circular, while Seattle's is strongly linear. (See Figure 3.) Houston has a well developed freeway network, with a full circumferential loop (I-610) and several radials that penetrate to the downtown area. It is also an area with modest bus service and is reported to be choking on its own automobile traffic. Seattle has a strong north-south axis, caused by the region's geography, with the freeway and public transportation systems following this pattern. Boston is a strongly radial region, but the freeway system does not completely reflect the pattern. The public transportation system is, however, strongly radial. Automobile congestion in Boston and Seattle is not as severe as in Houston.

For Boston and Seattle, the Consolidated Statistical Areas (CSA) are used, because in each case the SMSA *per se* omits a significant proportion of the regional settlement pattern. To wit, more than one-quarter of the population of the Boston CSA lies outside the Boston SMSA (in the Brockton, Lowell, and Lawrence-Haverhill SMSAs), while in the Seattle CSA somewhat over 20% lies outside the Seattle-Everett SMSA (in the Tacoma SMSA). On the other hand, the Houston SMSA contains some 93% of the CSA population (Galveston SMSA having only 7%).

Table 3: Travel-to-Work Data for Household Heads, 1976-1977
Selected SMSAs

Table 3a: Means of Transportation to Work

	Boston*		Seattle		Houston		US, in SMSAs	
	Number	%	Number	%	Number	%	no (thous)	%
Drives self	630,065	56	264,200	72	452,600	74	25,139	72
Carpool	121,745	11	56,600	15	116,500	19	4,942	14
Mass Transit	217,112	19	25,100	7	16,200	3	2,677	8
Bicycle, Motorcycle	na	-	3,800	1	3,900	1	283	1
Taxi	na	-	0	0	800	-	58	-
Walk	110,655	10	10,100	3	13,500	2	1,195	3
Other	22,529	2	1,000	-	1,000	-	165	-
Works at Home	20,410	2	7,100	2	7,700	1	493	1
Not Reported	na	-	800	-	1,600	-	72	-
TOTAL	1,122,516	100	369,000	100	614,000	100	35,022	100

Table 3a: Distance from Home to Work

	Boston	Seattle Number	Seattle %	Houston Number	Houston %	US no (thous)	US %
Less than one mile	NOT AVAILABLE *	15,100	4	31,900	5	2,144	6
1-4 miles		78,900	21	120,800	20	8,998	26
5-9 miles		69,400	19	107,800	18	6,863	20
10-29 miles		138,600	37	231,300	38	10,642	30
30-49 miles		12,600	3	32,000	5	1,266	4
50 miles or more		2,100	1	5,400	1	309	1
Works at Home		7,100	2	7,700	1	493	1
No fixed place of work		43,200	12	77,600	11	3,802	11
Not Reported		2,000	1	6,600	1	515	1
TOTAL		369,000	100	614,000	100	35,022	100
Median for Homeowners		11.6 miles		13.1 miles		9.0 miles	
Median for Renters		6.9 miles		8.1 miles		5.9 miles	

* Boston Annual Housing Survey: 1977 data not available until late April, 1980. Mode-split data above for Boston are from 1970 census and apply to all workers, not just employed household heads.

Source: Annual Housing Survey, 1976. (Note: The DOT Travel-to-Work Supplement to AHS provides data for other household members.)

More importantly, the high growth rates and the journey-to-work data in the small SMSAs surrounding the Boston SMSA show that they have become virtual bedroom suburbs to the Boston SMSA. This is very definitely not true in the case of the Galveston SMSA, which actually grew more slowly than the Houston CSA as a whole from 1970-1976. Moreover, Galveston is some 45 miles from the Houston CBD. In contrast, the satellite cities surrounding Boston (Brockton, etc.) are only 20 to 35 miles from the Boston CBD (and the population of the Boston CSA is more than twice that of the Houston CSA.) Tacoma is also only about 30 miles from the Seattle CBD and is now connected to it by a continuous band of urbanization. The last step in this urbanization fill-in process was the development of six tracts in the extreme southwest corner of the Seattle SMSA: the housing stock in these six tracts quadrupled between 1960 and 1970, and tract-level building-permit data since 1970 indicate that the stock will have increased another 80% by the time of the 1980 census.

Of the various other regions which were considered, several were judged to be nearly as suitable as Boston, Houston and Seattle. An abbreviated list of the "honorable mention" regions with some of their pros and cons is as follows:

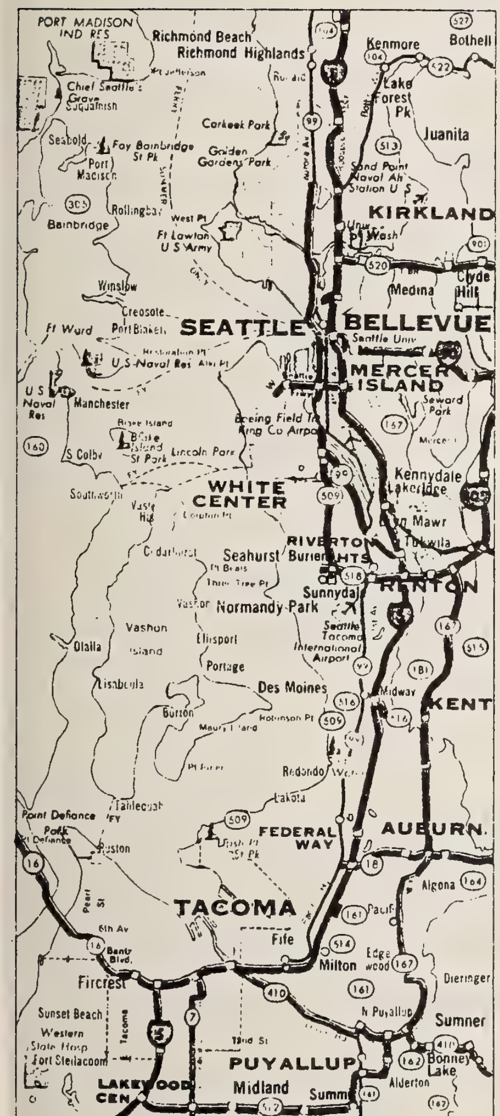
- o Atlanta: Annual Housing Survey data too old (1975-76, versus 1976-77 and 1977-78 for the regions chosen). An attractive advantage of Atlanta is its multi-jurisdictional, multi-county

FIGURE 3

MAPS OF THE THREE METROPOLITAN AREAS SELECTED

0 2 4 6 8

Scale in Miles



0 2 4 6 8

Scale in Miles (for Seattle and Boston)

geography, which would provide valuable small-area "handles" in manipulations of Public Use tapes, building permit data, etc.

- Denver: Lack of post-1970 building permit data at small area; lack of detailed land-use data. Also, the Annual Housing Survey does only a 5,000-unit sample in Denver (vs. 15,000 in the regions we have chosen.) A point in Denver's favor is an effective regional growth policy formulated by the COG and administered by the local jurisdictions.

- Phoenix: Too small; atypical to a degree as to vitiate the generalizability of research results to other regions. A "plus" is good tract-level building permits.

- San Francisco: Too much the West Coast twin of Boston. In the Bay Region's favor is the great amount of previous research in this area; however, this also argues for excluding it from our study, in that the generalizability of our findings to San Francisco will be facilitated by the previous research here.

- New York City: No coverage of the satellite SMSAs in Connecticut and New Jersey (except Newark) by the Annual

Housing Survey. Similar demographics and internal migration patterns to those in Boston make New York redundant to Boston and much more cumbersome data-wise. In New York's favor are extensive data resources and policy studies of the Tri-State Regional Commission and the Regional Plan Association.

Finally, considerations of balance among our three regions, as well as the individual merits of each region, entered into the final selection decision. For example, Houston provides a stronger contrast than Atlanta (the other leading contender as a Sunbelt/growing region) with Boston and Seattle in total size, growth rate and degree of reliance on mass transit.

TABLE 4

GLOSSARY OF TASKS

Phase I. RECONNAISSANCE

Task 1.1	General overview of the three metropolitan areas
Task 1.2	Acquire numerical data
Task 1.3	Define sectors of metropolitan areas
Task 1.4	Create 1980 data base
Task 1.5	Housing and growth policies within regions

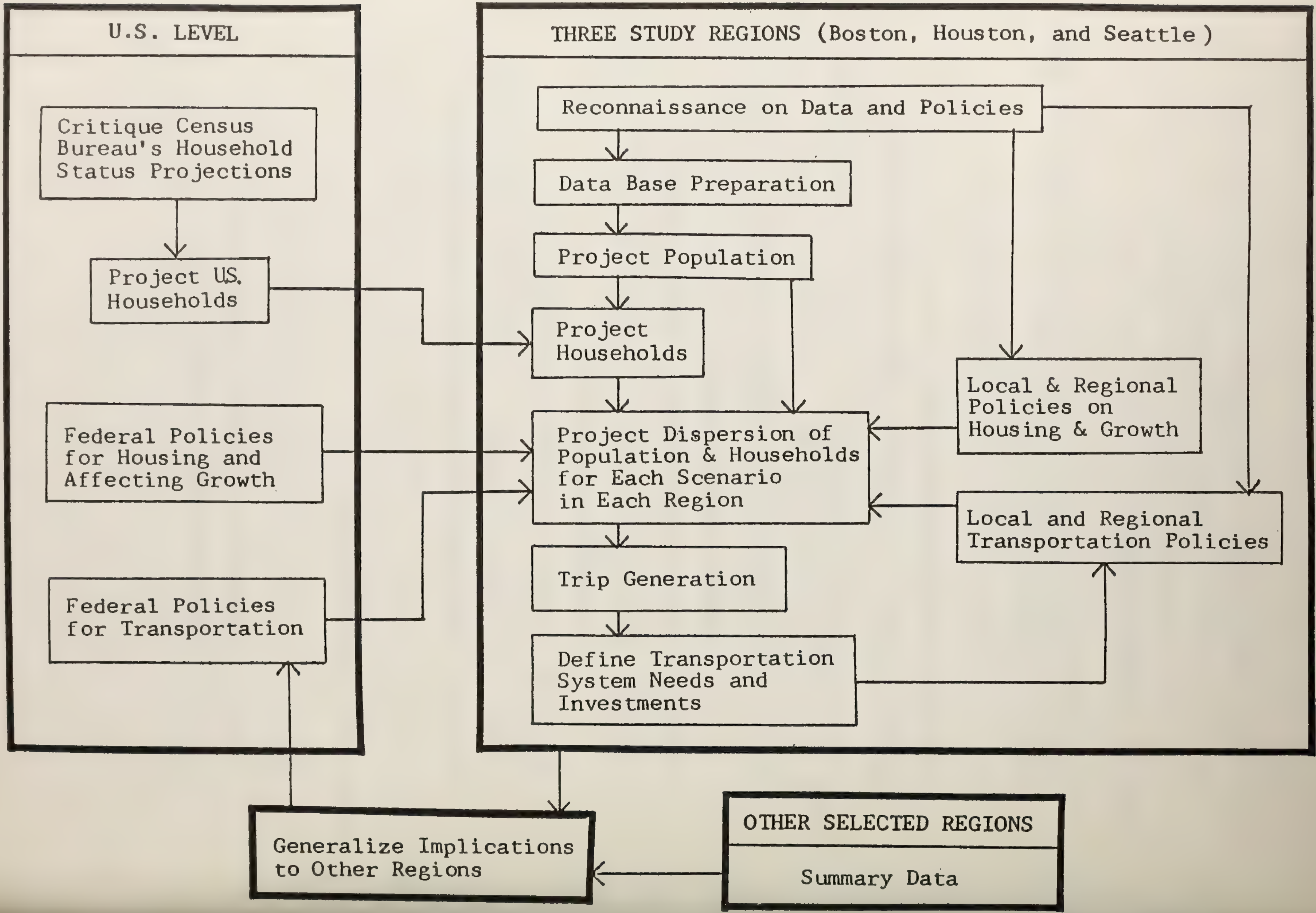
Phase II. ANALYSIS AND MODELING

Task 2.1	Critique Census Bureau's household status and household projections
Task 2.2	Project U.S. household configuration
Task 2.3	Project population and household status in the three metropolitan areas
Task 2.4	Dispersion modeling for scenarios
Task 2.5	Literature survey on residential preference
Task 2.6	Trip generation and VMT for each scenario
Task 2.7	Generalize research results to other regions

Phase III. POLICY ANALYSIS

Task 3.1	Housing and growth policy analysis
Task 3.2	Transportation policy formulation
Task 3.3	Transportation policy strategies

PROJECT FLOW CHART



Phase I. RECONNAISSANCE AND DATA COLLECTION ON THE THREE METROPOLITAN AREAS

This Phase deals with the development of a wide variety of region-specific information necessary for the research. It is comprised of five tasks which will deal with preliminary familiarization with the regions, gathering specific "hard numbers" needed to run the dispersion model, defining sectors within each region, preparing a 1980 data base for the dispersion model, and acquiring information on the local, state and regional policies on housing and growth. These tasks will be carried out through a combination of telephone contacts, personal contacts through site visits, literature searches, data collection, and data manipulation.

Task 1.1 Develop a General Overview of the Three Metropolitan Areas

This task consists of acquiring and preliminarily evaluating a variety of information from each region for the purpose of determining the important general characteristics of the regions from the standpoint of growth, dispersion, and transportation.

This entails a combination of talking with knowledgeable individuals, examining maps (e.g., the Census Bureau's Urban Atlas series), perusing whatever relevant data are easily obtainable (concerning, for example, building permits by jurisdiction for a recent year and by tract on a time-series basis), reading selected articles from the literature (e.g., on the existing region-specific transportation-land-use models, housing inflation, and environmental problems), etc. This task will also entail the first of three site visits to each region.

This task is now about 50% complete as a result of the work already done under the proposal-writing phase of this research.

It should be noted that INTERCHANGE associates are very familiar with the Boston region. One of the principals, Mr. Barber, is also familiar with the Seattle region as a result of previous research in the region on residential location decision-making while earning a degree in regional planning at the University of Washington.

Task 1.2 Acquisition of Numerical Data

This task consists of systematic acquisition of the numerical data needed to compare and evaluate the three regions, to build the 1980 data base, to feed the economic submodel, and to run the dispersion model. Specific steps are as follows:

1. Acquire the 1980 Census provisional "head count" data (on population and household) by tract for the three regions.

2. Arrange for access to 1970 Census Summary Tapes by tract in Houston and Seattle and by MCD in Massachusetts; to be used for population, household-status characteristics, household characteristics, and housing-stock characteristics.

3. Acquire hard copy of tract level 1970 Census data for these three regions.*

4. Acquire "street listings" and school-census data for selected towns in Boston region.

5. Acquire small-area post-1970 construction data (building permits, electrical hook-ups, etc.) for the three regions.*

6. Acquire small-area post-1970 data on housing values for the three regions.*

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*Indicates partial completion during writing of proposal.

7. Acquire small-area land-use and land-capability data for the three regions.

8. Arrange access to the Annual Housing Survey Public Use tapes (metropolitan sample series) and possibly the 1970 Census Public Use tapes for the three regions; to be used for additional cross-tabulations, especially as regards household and population characteristics by sector and housing values and costs by household income and other characteristics.

9. Acquire published Annual Housing Survey volumes for the three regions.*

10. Acquire and evaluate regional-level population projections for the three regions.

11. Acquire components-of-inventory change for housing stock for the three regions.

12. Acquire regional-level fertility, birth, death, mortality, and migration data;* migration data to include college and military sources.

13. Acquire Transportation Improvement Programs (TIP) for each region.

14. Acquire Transportation System Management (TSM) documents for each region.

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*Indicates partial completion during writing of proposal.

15. Acquire trip generation and VMT estimates made by each regional MPO.

16. Acquire state-level data on distributions of income by household characteristics for 1975 and subsequent data on personal income by state and region.

17. Acquire annual estimates (March or July 1) and projections of U.S. population, marital status, household status, and households by type.*

18. Acquire age- and sex-specific divorce and marriage rates for and mortality rates by marital status, age, and sex at U.S. level.*

19. Acquire U.S.-level on oil prices and vehicle operation costs by gasoline prices.

20. Acquire other data as necessary.

Many of the data sets listed above have actually been acquired (as indicated by asterisk) and all have been located. Sources are listed in Appendix C.

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*Indicates partial completion during writing of proposal.

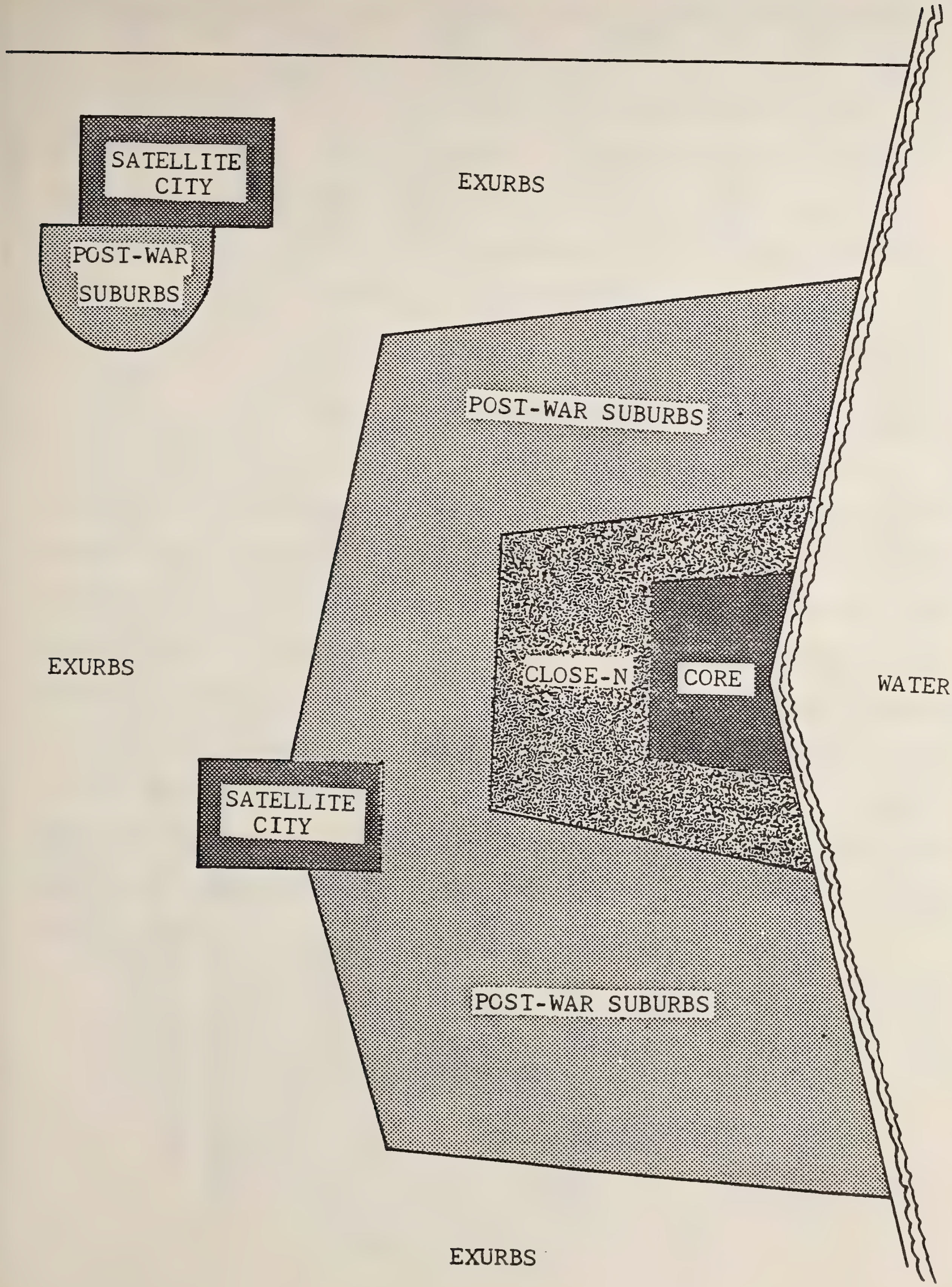
Task 1.3 Define the Sectors of Each Metropolitan Area

This task consists of assigning each census tract to one of the four (or five) sectors, namely the Core, the Cluster of Older Settled Neighborhoods (CLOSE-N), Postwar Suburbs, and the Exurbs (and, if applicable, the Satellite Cities). The Core, CLOSE-N, Postwar Suburbs, and Exurbs will be successive rings or bands, generally non-zero in width throughout (i.e., the Postwar Suburbs will not generally touch the Core). The Satellite Cities are remote from the Core and the CLOSE-N and are imbedded in the Postwar Suburbs and/or Exurbs. (See Figure 3 on following page.) Note that a separate group of Postwar Suburbs adjacent to a Satellite City may be defined, even though these suburbs are not contiguous with the Postwar Suburbs which surround the CLOSE-N.

Each tract will be assigned to membership in one of the sectors principally on the basis of density, housing-stock growth history, population age structure, and employment ratio. Table following indicates the characteristics of each sector in these respects. The criteria will be quantified on a region-specific basis. For example, in the Boston region the numerical values of the density classes would be approximately as follows:

Very high:	over 11,000 persons/sq. mile total land
High:	4,000 to 11,000
Moderate:	700 to 4,000
Low:	under 700

DIAGRAM OF GEOGRAPHIC SECTORS



	Core	CLOSE-N	Postwar Suburbs	Exurbs	Satellite Cities
Density	very high	high	moderate	low	high
Housing Stock Growth					
% built before 1950	very low	low	high	high or moderate*	low
Period of peak housing growth	NA	NA	1950-65	1965-80	NA
Population Age Structure (in 1970)					
Ratio: No. of females age 20-24 to no. age 10-14 and 35-44	very high	"normal"	low	low or moderate	"normal"
Ratio: No. of persons age 45-54 to no. age 35-44	NA	NA	higher	lower	NA
Percent Elderly	high	"normal"	low	low	"normal"
Employment Ratio (in 1970)					
Ratio: Destination JTW Trips to Origin JTW Trips	very high	high	low	low	high

*Very remote, low density areas of the region will be classified as Exurbs regardless of growth history.

The definition of sector boundaries will not be an extremely rigorous procedure. We will make a provisional assignment of each tract, calculate aggregate characteristics of the region, and then review tract assignments of all borderline tracts according to the criteria of Table   to determine where boundary changes are desirable. Isolated tracts with characteristics very different from their surroundings will be classified according to their surroundings in order to avoid geographic discontinuities.

The age structure will be given greatest weight in determining the boundary between the Postwar Suburbs and the CLOSE-N because of the paramount importance of age structure in the dispersion model, and because the split between the suburban/exurban sectors and the various city areas is of key significance in the desirability of residential location. On the other hand, in determining the boundary between the Exurbs and the Postwar Suburbs, the primary sorting criteria will be the distribution of the age of the housing stock and the ratio of persons age 45-54 to persons 35-44; these two variables distinguish the areas which were developed early in the post-war period from those which developed more recently.

Task 1.4 <u>Creation of 1980 Data Base for Dispersion Model</u>

The 1980 data base for the dispersion model consists of the population by age and household status (HHS) for each sector of the three metropolitan regions.

The total population, the household population, the total number of households, and the average household size will be accurately known at the tract level from the provisional 1980 census figures (see Appendix C). No characteristics -- not even age -- will be available before late 1981 or early 1982. Therefore, the essence of this task is to impute characteristics to the known totals. This will entail using a combination of projection techniques and intercensal estimates to assure reasonableness.

At the <u>regional level</u> satisfactory results for age structure may be obtained by a cohort-survival projection, using age-specific migration which is the sum of (1) an <u>a priori</u> age-specific net migration inferred from previous and recent rates (e.g., the 1965-70 census rates, the CWHS rates for recent years, the HEW state-to-state migration matrix for college students, and administrative-records estimates by the Census Bureau for recent years) with (2) an adjustment term consisting of whatever multiple of the national interstate mobility by age is required to make the total population agree with the known 1980 census totals for the region. (This simply reflects the fact that changes in the shape of the net migration curve by age between

two different time periods tend to be concentrated in the most mobile age groups.)

Household Status (HHS) at the regional level may be similarly inferred by a projection from the 1970 census, followed by an adjustment to force agreement with the actual total number of households and total group-quarters population as given by the provisional 1980 census totals. The simplest form of a projection from 1970 would be to extrapolate the 1979 HHS proportions to 1980 at the U.S. level and then assume that the regional changes in the HHS rates between 1970 and 1980 parallel the national changes, using the translation algorithm to be developed in Task 2.3. The distribution of household heads by age derived in this manner may be approximately verified by comparison with the recent Annual Housing Survey (AHS). The accuracy of verification is limited by the necessity to interpolate back to 1976 or 1977 and, in the case of the Boston region, by the fact that the AHS covers only the Boston SMSA, not the CSA.

As the final step in regional-level population estimates, the distribution of household sizes will be estimated from the regional distribution of HHS categories and the U.S.-level distribution of household sizes.

The increment in housing stock by type for each sector from 1970 to the time of the Annual Housing Survey will be known extremely accurately by scaling the annual tract-level building permit to force agreement with the 1970-1980 increment as computed from the provisional 1980 census data. The number of

vacant units by type can also be estimated with considerable accuracy (from the 1980 data on total vacancies, 1970 tract data by type and by owner/renter, annual data from the Current Housing Reports on vacancy rates by type, owner/renter, metro/non-metro, census division, etc., and of course the AHS vacancy data for the SMSA by various characteristics for the particular region). Therefore, we expect to have an excellent estimate of the number of households (which by definition is the number of occupied units) by sector for the date of the AHS.

We also expect to have a very accurate estimate of the total household population at the time of the AHS. The regression formula referred to above, which was developed by Dr. Sanders for making small-area population estimates, relates change in household population to changes in housing stock by type. Experience with this formula leads us to expect an R^2 exceeding 0.98 at the tract level and therefore negligible errors in the household population at the sector level.

The allocation of population and household characteristics for 1980 from the regional level down to the sector level will be inferred from the Annual Housing Surveys of 1976-77 (Houston and Seattle) and 1977-78 (Boston and Tacoma), the 1970 census, annual estimates of residential construction by tract, and the regression formula for estimating household population for small areas from housing stock change.

Broadly, a three-step procedure will be used: (1) Estimate the number of households and the household population by sector;

(2) estimate selected characteristics at the sector level from the AHS, and (3) observe any divergences in characteristics since 1970, and extrapolate these divergences forward to 1980 (while requiring agreement with the previously-determined regional-level characteristics).

We have already estimated characteristics in the Houston SMSA for the sectoral divisions provided by AHS, viz. "in central city" and "not in central city." This work is included as Appendix A. In brief, it shows that there has been an increase in both the absolute and relative concentrations of married couples and children in the suburbs and exurbs - specifically, the area "not in central city" - since 1970, and that the concentration of virtually every age group and HHS type has increased since 1970 on an absolute basis. The one major exception is very young married couples, which may be indicative of changes in timing of marriage and childbearing.

Note from Appendix A that certain household statuses are given with very broad age breakdowns, notably the heads of non-husband-wife households under age 65 (which comprise 30% of all household heads). To impute age detail to these household heads, it will be assumed that changes by sector parallel those at the regional level, as previously estimated.

To estimate characteristics for our sectors (Core, CLOSE-N, Postwar Suburbs, Exurbs, and Satellite Cities), as of the date of the Annual Housing Survey, a Baysian statistical procedure

will be used to apportion individual cases (households) from the AHS public use tapes to our sectors. This will entail (1) identifying housing characteristics which are differentially associated with particular sectors, (2) apportioning the population data for each household on the public use tape among the sectors in proportion to the number of housing units in the sector which have the same housing characteristics (note that this procedure for apportioning population among sectors artificially homogenizes the sectors to some extent and therefore results in an understatement of intersectoral differences in population characteristics), and finally (3) inflating inter-sectoral differences to correct for the homogenizing effect of the previous step. The characteristics thus estimated must be consistent with the accurate sector-level estimates of households and household population as described above.

It should be noted that each household on the AHS public use tape is coded by county and by whether or not in the central city (unless such coding would identify an area of less than 250,000 population, as would be the case for Chelsea, Revere, and Winthrop, which are in Suffolk County but not central cities), and therefore this allocation procedure will not generally mix data among counties. This of course tends to sharpen the discriminating ability of any selecting variable.

Comment: Sewering is an example of a housing variable which will be used for this procedure. In the Boston SMSA approximately 99% of the unsewered

housing units which are not in the central city (Boston per se) are in either the Postwar Suburbs or the Exurbs (according to the boundaries used by Dr. Sanders of INTERCHANGE in his 1975 Eastern Massachusetts dispersion model) and conversely 95% of the sewered housing units are in either the CLOSE-N or the Core. Thus, if sewering alone were used as a sorting variable - even absent the county identifier - then the characteristics of each unsewered household would be allocated 99% to the Postwar Suburbs and Exurbs and 1% to the CLOSE-N and the Core, while the characteristics of a sewered house would be allocated 5% to the former and 95% to the latter.

In contrast to Boston, the Houston region is much more extensively sewered; some two-thirds of the units outside the central city are sewered. We therefore expect that virtually all unsewered housing in the Houston SMSA will be in the Exurbs and conversely that virtually all the units in the Postwar Suburbs will be sewered for any reasonable definition of the sector boundaries.

For the Seattle region approximately 70% of all unsewered units in King County in 1970 were in some 49 tracts which were less than 50% sewered. With the exception of four tracts just south of

Seattle corporate limits near the tip of Lake Washington, most of these tracts will clearly be classified as Exurban, and conversely the decidedly remote and exurban tracts have uniformly very low sewering.

After completing the estimates of characteristics by sector at the time of the Annual Housing Survey, the 1980 characteristics by sector will be inferred by a simple extrapolation of the post-1970 intersectoral divergence (using, for example, the relative proportions as computed in Table A-1 and shown in Figure A-2).

Finally, the distribution of household sizes will be estimated. This completes the 1980 data base for the dispersion model.

Note that the use of proportions throughout to describe characteristics at the regional level automatically maintains consistency between the sectoral characteristics and the previously-determined regional characteristics.

Task 1.5 <u>Inventory Policies on Housing and Growth in the Regions</u>

This task entails acquiring information on the various state and local policies, practices and statutes which influence housing or growth in each region.

Among the types of information needed are:

- The statutory and constitutional division of authority among the state, counties, incorporated places, and other jurisdictions for growth regulation and housing policy.

- Existence and nature of policies at any of the above governmental levels which explicitly limit growth.

- Prevalence of various practices which are intended primarily to control growth, albeit indirectly (basically exclusionary zoning practices, including large-lot requirements, large setbacks, wide streets, granite curbing, etc.).

- Prevalence of other practices with other ostensible purposes which in fact are used to limit growth (e.g., unduly strict enforcement of environmental or health regulations, or unduly slow action at any stage in the permitting process).

- Variations across region of local attitudes towards housing and other types of growth.

It should be noted that the information above consists of a mixture of hard facts, opinions, and judgments. Although the precise approach to be used in gathering the above information will to some extent be determined by the initial familiarization work described in Task 1.1, it is expected that it will entail a combination of interviews (by phone and in person) with knowledgeable individuals, acquiring and digesting official documents and planning reports, and literature searches.

It would be beyond the scope of this project to analyze the growth policies, practices, and attitudes of all localities in our three regions on a comprehensive basis. Therefore we expect to select several representative communities in each region, upon the advice of knowledgeable individuals, and to generalize our findings in these communities to represent the various sectors of the regions. Finally, we will check our findings and generalizations for reasonableness with the same and other knowledgeable individuals.

Phase II. ANALYSIS AND MODELING OF GROWTH AND DISPERSION AND HOUSEHOLD BEHAVIOR

This phase deals with numerical analysis. The central task is modeling the future dispersion of population in the three regions, Task 2.4. Major inputs to the dispersion modeling are the regional data bases prepared in Phase I; the analysis and projections of household behavior in Tasks 2.1 and 2.2 below; the projection of regional-level population and household behavior in Task 2.3; analysis of survey research findings concerning residential preferences in Task 2.5; and the *a priori* policy analysis of Phase III.

The major outputs of the dispersion modeling are the projected dispersion per se of population and households by characteristics, translation of the projected dispersion into trips generated by sector in Task 2.5, and a discussion paper on implications of this research for other metropolitan areas in Task 2.7.

While the "bulge" in the age structure due to the baby boom is the major factor leading to a crunch in housing demand, analysis is expected to show that the demographic variables are relatively deterministic, i.e., the predictability of such variables as mobility, marital status, and household status is high in relation to the implications of these variables on dispersion and on transportation needs. Policies, on the other hand, are not deterministic. This research is expected to reveal that extremely diverse implications for growth patterns and transportation needs result from a plausible range of policies dealing with housing, growth patterns, and transportation.

Task 2.1

Critique the household estimates and projections prepared by the U.S. Census Bureau. Unpublished research by one of the INTERCHANGE associates indicates two likely problem areas: (a) measurement errors seem to exist for marital and household status in certain age groups in both the decennial censuses and Current Population Survey, and (b) unduly arbitrary extrapolation formulas seem to have caused discontinuities in projected headship rates by age, which in turn leads to spurious rates of increase in the number of households when the size of the age group is changing rapidly.

Task 2.2 <u>Project Household Configurations of the U.S. Population</u>

For all age-sex groups the proportions of persons in each of five categories of <u>household status</u> (HHS) will be projected:

1. Head of husband-wife family
2. Primary individual
3. Other head of household
4. Other member of household
5. In group quarters

The total number of households in the U.S. is simply the total number of persons in the first three categories of HHS. In addition, the number of wives of household heads will be independently projected by age of wife. An adjustment formula will be employed to equalize the number of husbands and wives (except military).

The principal analytical tool in the household status (HHS) calculations is the <u>transition probabilities</u> between different headship statuses. To illustrate, of all males in group quarters at age 20-24, a certain fraction will become heads of husband-wife family by age 25-29; this fraction is referred to as the transition probability for this particular change in HHS. The transition probabilities, which are obviously age- and sex-specific, can be estimated from longitudinal changes in headship rates, marital rates, and other HHS variables. Previous work by one of the associates of INTERCHANGE indicates that since 1960 the key transition probabilities have been more nearly stable

than either the household status proportions per se or the trends in the proportions.

Household headship rates will be projected using three distinct series:

1. An <u>expansive</u> series, which assumes a continuation of the trends of the last few decades toward rapid headship increases (mostly that young adults achieve headship earlier and the elderly maintain independent households longer). This series will approximate one of the higher Census Bureau series, but will eliminate the discontinuities by age.

2. An <u>expectations realized</u> series, which assumes that the non-heads in each cohort progress to headship at a pace similar to that of the last 15-20 years. This is a type of no-change scenario, in that it assumes that the headship opportunity of non-heads and their desire to exploit the opportunities will remain unchanged; the further assumption that this represents people's expectations results in the name of the series. However, this series may show increases in headship by age in the key age groups.

3. A <u>rock-bottom</u> series, which assumes that headship rates by age will be stable or will decline slightly.

The expectations-realized series will be generated by assuming that the transition probabilities in the future will be very

close to their values in the 1960s and 1970s (this will allow some further rise in the headship rates by age groups, since recent cohorts have generally been at higher headship levels than their age counterparts in previous cohorts). The household-status proportions for the expansive series will be chosen so that headship rates are (a) above the rates of the expectations-realized scenario, and (b) increasing over time for all age groups (but not necessarily all cohorts). For the rock-bottom series, the headship rates will be (a) lower than the expectations-realized series, and - as in the Great Depression - (b) slightly decreasing by age groups and increasing by cohorts over time, except possibly for the oldest cohorts.

Comment: In recent decades more of the increase in households has resulted from increasing headship rates than from increasing population. Although there are many reasons to doubt that this could continue to be true, the purpose of the expansive series is to explore the impact of this eventuality. At the other extreme, the rock-bottom series contemplates a depression climate at least as severe as in the Great Depression. The expectations realized is arguably the most plausible by far because it does in fact approximate actual expectations. Expectations are highly relevant because our political system is very much

oriented - both in general philosophy and multiple special programs and technical devices - toward allowing people to realize their expectations.

Task 2.3 <u>Prepare Projections of Population and Household Configuration in the Three Metropolitan Areas</u>

The population projections will use the cohort survival method at five-year intervals in both age and time to the year 2000, with illustrative adjustments for migration. In each time iteration the <u>in</u> <u>migrant</u> population will be kept separate from the <u>stayer</u> population (total less deaths and outmigrants). Fertility series II (replacement level) will be used. Student and military populations will be treated by direct substitution rather than cohort survival.

Household composition in each region will be assumed to change over time in a manner which roughly parallels changes at the national level. A simple translation algorithm will be used to express this analytically, taking care to treat near-zero and near-saturation cases reasonably.

<u>Comment</u>: Alternative fertility series are not needed because the transportation implications of the model are expected to be sensitive predominantly to changes in the household characteristics of those who are or will be adults during the next decade or two - i.e., to the behavior of people who are already born rather than to the number of babies who will be born during this interval. (Since the lower fertility series are associated primarily with fewer children per family

rather than higher incidences of childlessness, a single fertility series can accommodate a wide range of household and family configurations.)

The reason for doing separate accounting on the stayer and (gross) inmigrant populations is that the level of regional (gross) outmigration may significantly influence opportunities for residence seekers and that intra-regional movers may be more likely than (inter-regional) inmigrants to preempt the most desirable housing locations. Such an effect would mean that the proportion of the baby-boom generation which is forced to the outer suburbs would be negatively correlated with the level of interregional migration. More broadly, for any given level of <u>net</u> migration, the degree of dispersion by age may be sensitive to the size of the <u>gross</u> flows. Therefore separate accounting will be done unless insensitivity can be demonstrated.

Task 2.4 Prepare Illustrative Projections of the Dispersion of Population and Households in the Three Metropolitan Areas.

The projections will be age-specific for four, and possibly five, subareas, as described in Task 1.3 above, namely the exurbs, the postwar suburbs, and three city areas; the city areas will be a central core, the CLOSE-N, and non-contiguous satellite cities (where applicable). Three scenarios will be prepared:

(a) A high-dispersion scenario, with future growth concentrated in the exurbs (which will experience extremely rapid housing growth) and with low housing growth in both the city and the postwar suburbs;

(b) A low-dispersion scenario, with somewhat lower housing growth in the city, but still slow growth in the postwar suburbs;*

(c) A balanced-growth scenario, in which the postwar suburbs will experience moderate housing growth, mostly at the expense of exurban growth.

The expectations-realized household-status series will be used for all dispersion scenarios. In addition, as a sensitivity check, the high-dispersion scenario will also be run with

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*One might expect a "low-dispersion" scenario to feature low housing growth in suburbs and exurbs and high growth in cities; this, however, is unrealistic. Existing high densities in the cities of major metropolitan areas limit their physical capacity to absorb further growth and suggest that, even under the best of circumstances, a major part of future household increases must be accommodated in suburban and exurban areas.

the expansive household status series and the low-dispersion scenario will also be run with the rock-bottom household status series.

This task builds directly on previous research by one of the INTERCHANGE associates. In 1975, while employed by the Massachusetts Office of State Planning, Dr. Sanders constructed the Eastern Massachusetts Macro-Metro Region (EMMMR) model to describe population dispersion in Eastern Massachusetts (for the purposes of projecting regional population dispersion and formulating growth policy). Therefore this task begins with generalizing the earlier model and improving its ability to test sensitive variables.

Comment: The balanced growth scenario should in no case be regarded as the "most likely" future just because it lies, in a sense, between two extremes. Its distinguishing feature - substantial housing growth in the postwar suburbs - is unlikely to occur except as a result of most deliberate government policy.

A brief description of the model follows.

Overview of the Dispersion Model

The purpose of the model is to allocate the future regional population by age among the sectors (geographic area) of the metropolitan area in a manner which takes account of both (1) how

people of specific ages want to distribute themselves geographically, paying particular attention to the family-settlement stage of life, and (2) the new constraints on location, paying particular attention to the escalating conflicts between the barriers to growth in the suburbs and the enormously increased family housing needs of the baby-boom generation.

The main driving force of the model is the apparent desire of the majority of people at the family-settlement stage to locate in the suburbs.

The methodology of the dispersion model may be summarized in five major steps:

Step I: Calculate the potential demand for space in suburban and city sectors, assuming (a) that middle-aged and older people will continue to have very low mobility and will therefore create relatively few housing vacancies via mobility, and (b) that people who are younger than middle-aged would, absent changes in economic limitations, distribute themselves between the city and suburbs in a manner similar to that of people in corresponding age groups in the recent past. This step is carried out recursively in five-year intervals.

A somewhat more detailed description of this step appears in Appendix B.

<u>Step II:</u> Enumerate and evaluate various supply-side considerations, including economic factors and policy measures, which are applicable to the various sectors. Among the factors to be considered are:

1. Local no-growth policies in the Postwar Suburbs.

2. Less severe local growth restrictions in the Exurbs.

3. Actual limitations on buildable land in the Cities and Postwar Suburbs.

4. Changes in various cost factors, including energy, transportation, mortgage money, and housing price.

5. Existing transit availability and likely future changes in transit availability.

Factors in groups 4 and 5 above will be assigned on the basis of plausible "market behavior" and deliberate federal and state policies which are intended either to alleviate the housing crunch or to promote good regional development patterns, or both (e.g., policies designed to make housing more affordable, to stimulate empty-nester mobility, or to damp out the cyclical nature of the construction industry). With regard to 3 above, estimates will be made of conditions required for conversion of existing low-density neighborhoods to higher density.

The next three steps consist of allocating the population and households among the sectors for three distinct sets of

assumptions, which differ in their degree of dispersion. In each case, the step entails relating supply considerations (policy measures, prices etc.) and demand considerations (demography, income, preferences, etc.) via an analytical economic submodel and then recursively running the dispersion model per se to allocate the future regional population and households among the sectors, i.e., the economic submodel essentially calibrates the dispersion model.

Comment: A number of analytical models have been developed in the urban economics literature for explaining the observed spatial distribution of households in a metropolitan area.* While very generalized, these models make it feasible to generate the actual location of households by income and family characteristics on the basis of a few statistically-derived parameters in the metropolitan areas. The housing stock is described by its quality (which may include neighborhood characteristics), associated transportation costs, and price.

To construct our economic submodel, a set of prices for the individual sectors will be established as follows: The offer price of each household by age, sex, income, etc. will be

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*See, for example, R.F. Muth, "The Allocation of Households to Dwellings," Journal of Regional Science, Vol. 18, No. 2, August 1978, pp. 159-178.

derived statistically. The various supply-side considerations associated with the different scenarios would be employed to generate sets of <u>supply prices</u> for housing in individual sectors. The mobile population would then be allocated by a numerical routine according to a rule whereby the available housing goes to the highest bidder, consistent with the supply price. The term "available housing" consists of the vacancies which will occur as a result of projected mobility (assumed to be exogenously determined) and new construction, the amount and location of which will be determined by supply-demand relationships.

Note that the model assumes that some mover households will prefer inner-city locations - primarily young primary individuals and young couples - notwithstanding the fact that suburban and exurban locations are the preferred locations for the majority of households.

This approach would make it possible to enter directly in the allocation routine, via the offer price, assumptions about factors affecting transportation costs, e.g., oil prices, mass transportation characteristics, and mortgage-interest subsidies. The supply prices

would reflect the influence of (out-mover) mobility, new construction/conversion rates, and growth policies.

Step III: To generate a High Dispersion Scenario, assume that severe local no-growth policies and limitations on available land in the Postwar Suburbs will restrict the supply of housing in this sector and that any excess over the potential demand as calculated in Step I above will be satisfied in the Exurbs. For example, neglect supply-side considerations in all sectors except the Postwar Suburbs, and assume that the Outer Suburbs is the preferred location of those who comprise the excess demand for the Postwar Suburbs. This step is also recursive.

Step IV: To generate a Low Dispersion Scenario, choose one set of supply-side assumptions. This set of assumptions must meet the following criteria:

1. The set of assumptions is plausible in the sense that it would not be startling if the assumptions turn out to be accurate, both individually and in combination. Note that this means we will not posit simultaneous worst-case assumptions for all factors, since this could be implausible.

2. The set of assumptions has restrictive implications on growth in both the Postwar Suburbs and the Exurbs.

3. Its implications for restricting growth in the Exurbs are of above-average severity in comparison with other plausible sets of assumptions.

4. It specifically includes the assumption that local no-growth policies in the inner suburbs are very severe and that no new state or federal policy measures have been implemented to target growth into the Postwar Suburbs.

(This does not mean that we will simply assume slow growth or no growth in the Postwar Suburbs. Rather, the growth rate will be estimated on the basis of economic pressures; the possibility of accelerated growth in this sector cannot be excluded *a priori*.)

Allocate population recursively, given these assumptions.

Step V: To generate a Balanced Growth scenario, relax condition 4 above by assuming a moderation of local no-growth policies and the implementation of a bundle of federal and state policies designed to foster Postwar Suburban growth while controlling sprawl in the Exurbs.

Allocate population recursively, given these assumptions.

Task 2.5 Review and Summarize Existing Literature on Residential Location Preferences.

Identify the key intervention points in transportation that could be used to influence these residential preferences.

Comment: Considerable skill and insight are required to interpret the extant body of survey research on residential preference. This field has evolved rapidly in the past 5 or 10 years, as successive researchers have remedied major oversights of previous studies. Although all surveys since the first Roper survey in 1947 had consistently shown a small-town/rural yearning, it was not until 1972 that the difference between remote small towns and small towns near large cities was probed, with the result that a clear preference for urban fringe locations was shown. Subsequent studies have distinguished between (1) a pure wish to live in a given location and the willingness to trade off location against long commutes or lower income, and (2) important differences between the responses of potential movers and of the general population, and (3) preferences for varying degrees of remoteness from major cities. The findings are still somewhat unsettled in some of these respects. In particular, the difference between truly rural areas

and fringe locations is still blurred because of unduly-constricted definitions of SMSA, which tend to result in classification of fringe areas as rural.

Perhaps the most serious oversight in residential-preference research is the failure to regard as normal the young-adult migration into large urban centers at about age 18 and then back out a few years later, and the concomitant failure of researchers to phrase residential-preference questions to these individuals in a manner capable of distinguishing where the respondents want to live in the next few years from where they want to settle down ultimately. Therefore, the survey research results for young adults are not comparable with those for older age groups. Since the peak of the baby boom was still below age 20 when the most recent survey research was done, the process of comparing the baby boom's residential preferences with those of previous generations will not be trivial.

Task 2.6 Translation of Housing Location Choices into Trip Generation and Vehicle Miles of Travel Estimates.

Based on standard trip generation factors and factors for vehicle miles of travel, the travel demand requirements of each development scenario will be estimated. These will serve as benchmark data for evaluating transportation policy choices. Data for the three study areas will also be used to establish differences between the prototypical development scenarios.

Trip generation analysis will use data from the following sources:

- o Institute of Transportation Engineers, Special Report on Trip Generation (1976). Data are stratified by residential type which can be related to average densities. Generation rates will therefore vary by geographic sectors for residential uses, depending on overall densities for those sectors.

- o Special Traffic Generator Study (1974), prepared by the Delaware Department of Highways and Transportation. Report Number One deals with residential generation, and shows how it varies by different density and building types.

- o Trip generation studies done as part of area-wide transportation studies for the Boston, Seattle and Houston Metropolitan Areas. For example, in Boston trip generation rates for downtown, urban, suburban

and rural areas are estimated separately. The correspondence of these rates with the two other data sources will be explored and the most reasonable set of rates for each residential category will be used.

This analysis will result in different levels of total trips for each metropolitan area, depending on development scenario. Transportation policy implications of these varying levels will be analyzed in Tasks 3.2 and 3.3. Table 6 shows examples of how trip generation rates vary by different residential density categories.

Vehicle miles of travel for each region for each scenario will be based on growth factors yielded from the area-wide transportation studies already done in each area. VMT factors for each of the broad sectors defined for our study will be used.

TABLE 6

TRIP GENERATION BY RESIDENTIAL DENSITIES

A. National data compiled by the Institute of Transportation Engineers (various studies from different regions).

Dwelling Unit Types	Associated Residential Densities	Automobile Trip Ends/Day
Single Family Detached	0.5 to 3.9	10.0
Town Houses	4.0 to 7.9	5.6
Low Rise Apartments	8.0 to19.9	5.4
High Rise Apartments	20.0 and over	4.3

B. Data compiled by the State of Delaware for its urban areas

Residential Density (Housing Units/Acre)	Automobile Trip Ends/Day
2.0 or less	11.9
2.1 to 4.0	10.9
4.1 to10.0	9.2
10.1 and over	7.3

C. Boston area data trip generation analysis

Residential Area Type	Total Trip Ends Generated/Day		
	Work	Shopping	Recreation
Central Business District	.562xPOP	.430xPOP	.201xPOP
Urban Areas	.559xPOP	.361xPOP	.202xPOP
Suburban Areas	.542xPOP	2.012xCARS	1.001xCARS
Rural Areas	.493xPOP	1.912xCARS	.926xCARS

POP = Resident Population: CARS = Automobiles Available

The data show that as residential densities increase total trip making increases; while automobile trip making decreases.

Task 2.7 <u>Prepare a Discussion Paper Outlining How the Conclusions (as opposed to the methodologies) of the Analyses in the Above Tasks can be Generalized to Other Metropolitan Areas</u>; illustrating with detailed data from two other metropolitan areas (including detailed age structure data by sectors and recent housing and construction data by type) and summary data for about ten other metropolitan areas.

<u>Comment</u>: It is anticipated that the central point of this discussion paper will be that the maturation of the baby-boom is a phenomenon of such magnitude and universality in the U.S. as to be the dominant factor in the development patterns of metropolitan areas throughout the U.S. in the next decade. The dual potential for highly dispersive growth and a severe family housing crunch - with large concomitant uncertainties - is expected to prevail in nearly all metropolitan areas. The comparative importance of interregional migration will be explored, but it is anticipated that this phenomenon will be secondary to the direct baby-boom effects in importance for all but a handful of metropolitan regions. Assuming these anticipated conclusions are indeed reached, then the results of the modeling for the two areas will be very highly generalizable to other metropolitan areas.

Future research might be productive into how the models in the UTPS package can more realistically incorporate the effects of maturation of the baby boom.

Phase III: POLICIES FOR HOUSING, METROPOLITAN GROWTH, AND TRANSPORTATION

This phase deals with policies and their implications. It will explore both the conflicts and the opportunities for mutual support among major policies designed to address problems in the areas of housing, growth patterns, and transportation at various levels of government. Work will not be limited to existing policies and policies under consideration, but will also include likely policy responses to problems which we can foresee.

We will indicate how major policies aimed at issues of housing and metropolitan growth are likely to actually affect metropolitan growth patterns. We will describe the transportation policies needed to support the respective growth patterns, and indicate the feasibility of adopting flexible transportation policies in order to cope with the probable situation of large uncertainty as regards actual metropolitan growth patterns. In particular, we will explore the proposition that the degree of uncertainty about future growth patterns makes it unwise to adopt transportation policies which are designed for any single assumed future, but rather requires the adoption of transport policies designed to hold adverse effects to acceptable levels in worst-case situations, as regards mismatches between transportation policies and the growth patterns which actually unfold.

Work done in this phase will be closely integrated with the Phase II work. It should be pointed out that the main focus of this overall project is the growth pattern implications of the baby boom. Drawing the transportation implications from these patterns receives secondary attention, both in terms of level of detail and depth of methodology. A rather "broad brush" is applied to transportation policy analysis in this proposal. Treatment is multi-modal and general.

Task 3.1 Housing and Growth Policies

Examine major policies and policy objectives which deal primarily with housing and growth patterns in terms of their probable implications on actual growth patterns, transportation needs, and transportation system investments.

The federal, state and local policies in this area reflect a very complex montage of overlapping and conflicting objectives of various groups. A brief list of the most important objectives would have to include:

**1. Make home ownership more affordable, especially for young families.

2. Protect real estate values of present owners.

*3. Stimulate or stabilize the construction industry.

**4. Contain the escalation of construction costs.

**5. Make the construction and management of market-rent stock more attractive to investors.

6. Stabilize rent increases (ie, rent control).

**7. Provide assistance to renters.

8. Prevent condominium conversions.

*9. Revitalize the inner city.

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* = Mixed federal and state concern
** = Primary federal concern
No asterisk = essentially a non-federal concern

*10. Prevent "displacement" of low-income groups in the inner city ("Gentrification").

11. Encourage "good" regional growth patterns.

12. Stop growth in my town.

*13. Insure equal housing opportunity for minorities ("open housing").

*14. Provide assistance and relief to the elderly, handicapped, and other groups with special needs.

15. Discourage "overconsumption" of housing, especially by the elderly.

Since most of the extant analysis of the various existing and proposed policies in housing and growth policy focuses on their nominal and explicit objectives, our task will be to extract their transportation implications. We will indicate which housing and growth policies would have major implications for transportation and which would not. Further, we will make statements about which of the transportation-sensitive growth and housing policies are likely to be continued, adopted, or abandoned. It is expected that the policies will vary in each of the three metropolitan areas and that each can serve as a prototype for similar areas.

<u>Comment</u>: As an example, the President of the Federal Home Loan Bank recently suggested subsidies on mortgage interest for new rental stock in order to meet the "crisis" housing needs of middle-income people <u>as a substitute for home ownership</u>. If such a proposal were translated into federal policy, it would have gargantuan implications for metropolitan growth patterns and for transportation requirements. To wit, such a policy - which would affect primarily the baby-boom generation - would tend to favor a "balanced growth" scenario, as defined in Task 2.4 above; i.e., it would accelerate growth in the Postwar Suburbs. Not only would the housing units built under this plan require less space than alternatives, but - very importantly - a massive federal campaign aimed at solving the middle-income housing crisis could be expected to be far more acceptable in the suburbs than developer-initiated attempts to site rental housing there.

On the other hand, the baby-boom generation may strongly resist becoming a generation of renters. If political pressures resulted in a diversion of resources of this magnitude (a

subsidy of up to 4 points on the mortgage rate) into subsidies for home ownership, then rapid dispersion to the Exurban Areas would very likely ensue. Several states, including Massachusetts, already have mortgage-subsidy programs for homeowners (with generous ceilings on income), but they are so very limited in scope that they would have no dispersive effect unless greatly expanded.

At the other extreme, U.S. Representative Al Ullman (D., Oregon, and Chairman of House Ways and Means Committee) has even opposed federal involvement in mixed-income housing, arguing that the only appropriate federal role in housing is to help the poor. The so-called "Ullman Bill" would make new Section 8 housing "all poor," terminate the various state homeowners' mortgage-subsidy programs, and preclude any federal program of this nature. Since many observers believe that the mixed-income feature of Section 8 is essential for even the limited acceptance which is accorded this program in middle-income areas, it is reasonable to project that passage of the

Ullman Bill would lead to a significant concentration of the poor in existing low-income neighborhoods, which would generally make the urban core much more dense.

In contrast, "overconsumption" of housing is an issue which has so far received virtually no attention outside of the community of housing specialists, and even they have tended to ignore the middle-age "empty-nesters" and focus instead on the elderly. This is, however, a pivotal issue in the resolution of the family housing problem of the baby-boom generation, and it will therefore probably become more prominent as a policy issue in the very near future. A continuation of low levels of empty-nester and elderly mobility (which is a virtual surrogate for overconsumption) would have strong dispersive implications, while a sharp increase in empty-nester mobility could significantly augment the prospects for a "balanced-growth" scenario. (However, the sensitivity of dispersion to middle-age mobility would probably be reduced if the crunch takes the form of precluding homeownership to a large fraction of the baby-boom generation.)

Stimulating empty-nester mobility would require both (1) carrot/stick financial incentives making mobility financially attractive, and (2) mechanisms to actually provide attractive alternative housing options within the same or nearby neighborhoods. These would require, respectively, (1) changes in federal and state tax laws (which now provide strong incentives to reduce "empty nester" mobility, on the theory that middle-aged and elderly people have special hardships), and (2) state enabling legislation to allow localities to acquire sites for development of housing suitable for middle-aged "empty-nesters" and having financial and locational advantages to the occupants comparable with remaining in their present homes.

Any successful program of this nature for stimulating "empty-nester" mobility would tend to favor a "balanced-growth" scenario. This is because the "empty-nesters" would primarily stay in their present neighborhoods, while freeing family housing

for the baby-boom generation. This process is one of the very few ways for fostering substantial housing growth in the post-war suburbs.

Another possible measure for increasing the development attractiveness of the post-war suburbs would be to require the internalization of the cost of any additional infrastructure requirements of new housing. This might entail some kind of state-imposed surcharge for building in areas without excess capacity and perhaps a corresponding rebate for building in areas presently having excess infrastructure capacity.

The Postwar Suburbs are much more likely than exurban localities to have excess capacity, especially in school facilities, which is by far the most expensive component of the infrastructure requirement of a housing unit (accounting for roughly half the total cost). It should be noted that the excess school capacity in the post-war suburbs is a result of the fact that this is where half the baby-boom generation grew up.

Task 3.2 Transportation Policy Formulation

Formulate those transportation policies that are supportive of the housing locational choices likely to be made by people under each of the three development scenarios. Combinations of policies that match and reinforce each other would be selected. The product of this task would be an elaboration of the transportation actions and program emphases necessary to help achieve each of the development scenarios.

Transportation impact research will provide the basic information on how various policies affect urban growth. Examples of the types of material to be used are:

- The Interstate Highway System and Urban Structure: A Force for Change in Rhode Island. Dieter Hammerschlag, Brian Barber and Michael Everett, University of Rhode Island, 1976.

- "Urban (Metropolitan) Impacts of Highway Systems," Stephen H. Putnam, The Urban Impacts of Federal Policies, Norman J. Glicksman, ed., The Johns Hopkins University Press, 1980, pp. 376-397.

- "Impact of Federal Rail Transit Improvement Program on Urban Spatial Structure," David E. Boyce, The Urban Impacts of Federal Policies, Norman J. Glickman, ed., The Johns Hopkins University Press, 1980, pp. 398-420.

Impact studies in each of the three metropolitan areas will be reviewed as part of this task and introduced into the analysis of how transportation policies could be recombined to better support the development scenarios. At this level of abstraction the transportation policies will be expressed in terms of major investment programs such as heavy rail, light rail, express bus, local bus and paratransit on the public transportation side, and freeway, arterial and local road improvements on the private side.

It is the purpose of this task to match up proper transportation policies with metropolitan growth patterns. Poor matches will be highlighted as well as good matches. For example, it will not be intelligent policy to continue to build heavy rail networks in regions where the growth policies of the Postwar Suburbs will force residential development into dispersed Exurban locations.

Task 3.3 Transportation Policy Strategies

Because considerable uncertainty will be associated with the overall social response to the emerging demographics and resulting housing "crunch," it is important that flexible options be defined for transportation policies. To the extent possible, then, the flexibilities of each combination of transportation policies will be identified. For example, investment in heavy rail is extremely inflexible, while investment in buses is flexible. A strategy embodying high levels of flexibility is superior given a relatively high degree of uncertainty about the spatial pattern of households. This task is an extension of Task 3.2. Task 3.3 goes beyond identifying transportation policies into recommending those best suited to each set of conditions.

Comment: General transportation policies are identified initially for the project in Task 3.2. These would be analyzed and elaborated and made more area-specific in Task 3.3 in terms of the development scenarios as outlined in Task 2.4 and the trip generation analysis of Task 2.6. Examples from the three metropolitan areas selected as data sources would be used to make specific points in the analysis. The policies are:

(1) Continue primary investment in roads and highways. Also identify specific geographic sectors (e.g., suburban or exurban areas) for improvements in roads.

(2) Favor public transportation including heavy rail, light rail bus facilities on highways, local bus and para-transit. Analysis will use information on trip generation and residential density to define a mix of public and private transportation services which seems best suited for each sector in each of the three metropolitan areas. It is not expected that either public or private transportation modes will be exclusively recommended for each area, but rather that a mix of services, with the balance tipped toward one mode or the other, will emerge from this analysis.

(3) Aid in the creation of more desirable living environments in urban areas by creating auto-restricted zones. These include not only full or partial pedestrian malls in commercial areas, but also cul-de-sacs created from former through streets in residential areas.

(4) Enlarge the powers and abilities of transportation agencies and public transit authorities to become property development organizations so they can initiate <u>and</u> implement joint development projects.

(5) Support and enlarge regional transportation planning agencies where the 3-C process, unified work programs, TIP and TSM preparations are vested. Land development plans and programs and multimodal transportation planning functions are the responsibility of these agencies. All the elements including project review (the A-95 process) come together in the regional planning agencies. Many are woefully understaffed, poorly staffed and underfunded. For many, funding is sporadic and uncertain. In some cases the MPO (Metropolitan Planning Organization) for transportation is not the same as the general A-95 agency (the RPA). This situation considerably lessens the chance that proper coordination between land development and transportation planning and programming will occur.

> The U.S.D.O.T. can and should bring pressure to insure proper authority and funding are vested in the regional planning agencies. The present energy and economic imperative capturing national attention, as well as an articulation of the housing and growth policy "crunch" now being felt in its initial phase, should provide ample justification for the U.S.D.O.T. doing its part in reforming the context in which transportation planning and programming decisions are made. A critical task in this effort is to properly document and publicize the housing and growth policy "crunch".

These policies will be reviewed by local transportation planners in each region. Their reactions will be included in the study. Their sense of reality about each of our recommendations will be noted, as will the relative departures from existing plans and policies contained in our analyses and recommendations.

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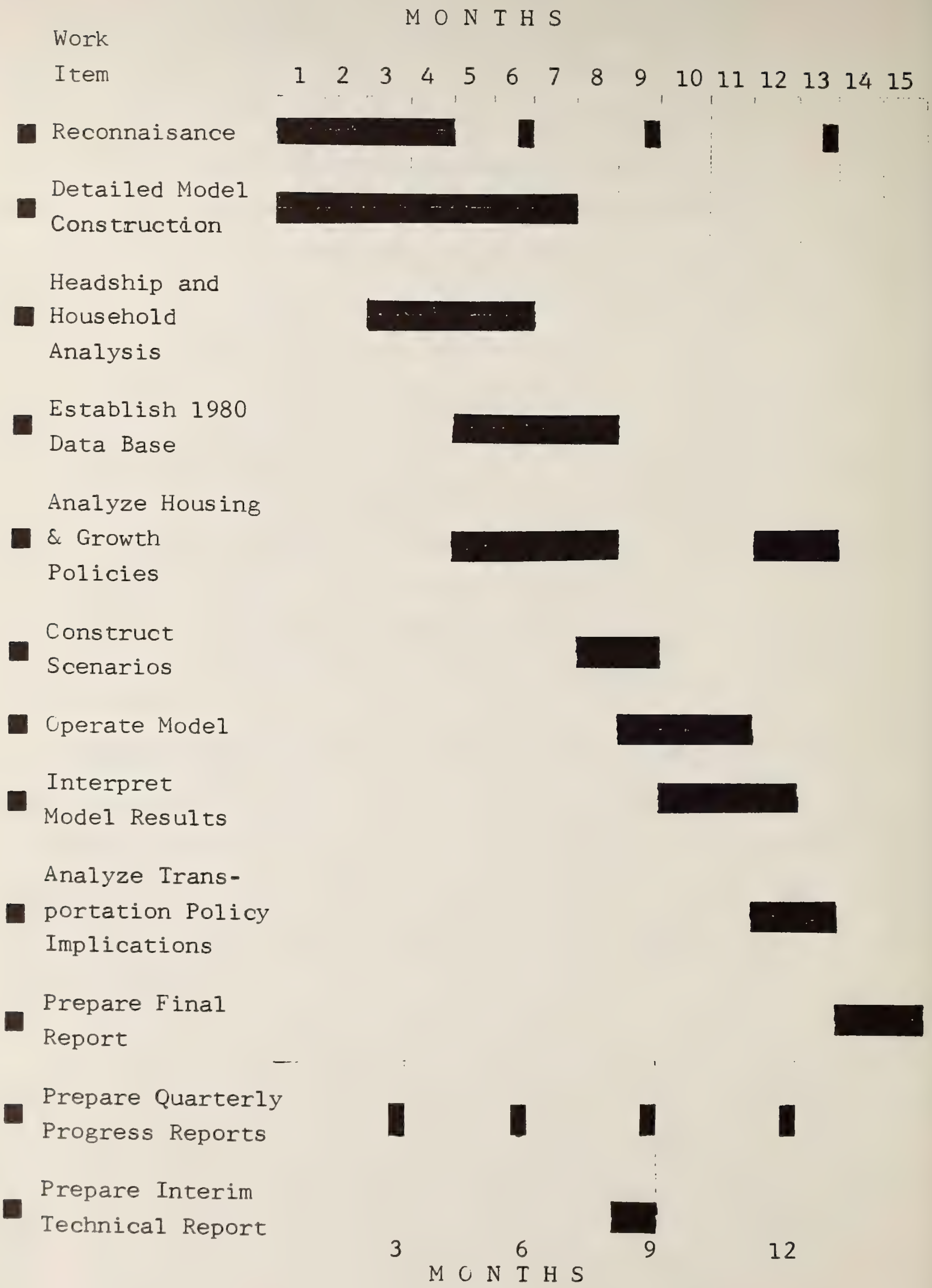
Figure 6: MASTER WORK SCHEDULE



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APPENDICES

APPENDIX A

Dispersion of population by age and household status (HHS) within the metropolitan areas of the U.S. in the 1970s may be estimated from the Annual Housing Surveys. Part A provides data for 1970 and the survey data on persons in selected age and HHS groups for the entire SMSA, "in central cit(ies)" and "not in central city(ies)".

Taking the latter as "suburban," we have calculated the <u>suburban partition proportion</u> in the Houston SMSA for each age and HHS group provided by AHS; see Table A-1.

For example, the table shows that, of the married males who were household heads in the Houston SMSA in 1976-77, 52.7% lived outside the central city (Houston). The corresponding figure for 1970 was 43.1%, indicating considerable dispersion in this age-HHS group. Of the entire household population of the SMSA, 43.3% lived outside of Houston in 1976-77, versus 37.9% in 1970, also indicating dispersion, albeit at a lower rate. Thus married male family heads age 30-34 were overrepresented in the suburbs by a factor of 1.217 (= 52.7/43.3) in 1976-77, versus 1.138 in 1970, as shown in the last two columns of Table A-1.

From Table A-1 and Figure A-1 it is clear that the suburban partition proportion of virtually every age and HHS type has increased since 1970, the major exception being very young married

TABLE A-1

SUBURBAN* PROPORTION OF PERSONS BY SELECTED AGE AND HOUSEHOLD STATUS, 1970 AND 1976-77

HOUSTON SMSA

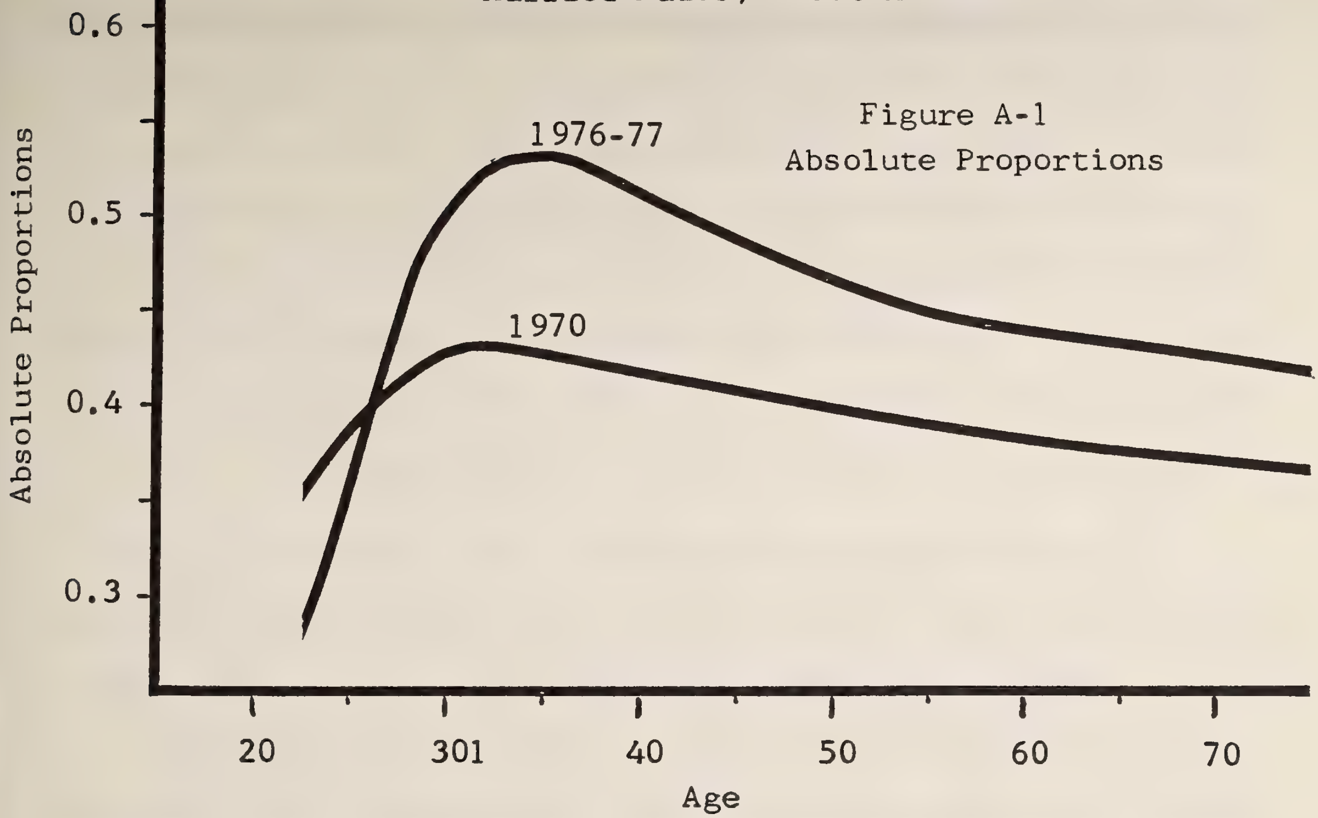
	Absolute Proportion		Relative Proportion	
	1976-77	1970	1976-77	1970
Household Population	.431	.379	1.000	1.000
Household Heads	.395	.356	.911	.940
Married Men, Wife Present				
Age < 25	.267	.352	.616	.929
25-29	.435	.408	1.004	1.077
30-34	.527	.431	1.217	1.138
35-44	.513	.417	1.184	1.101
45-64	.450	.397	1.039	1.048
65+	.425	.360	.981	.951
Other Male Head				
Age < 65	.274	.280	.633	.739
65+	.35*	.292	.81*	.771
Female Head				
Age < 65	.278	.245	.641	.647
65+	.28*	.295	.64*	.779
Primary Individuals				
Age < 65	.214	.209	.494	.551
65+	.332	.309	.767	.813
Children				
Age < 6	.466	.402	1.076	1.062
6-17	.492	.410	1.136	1.082

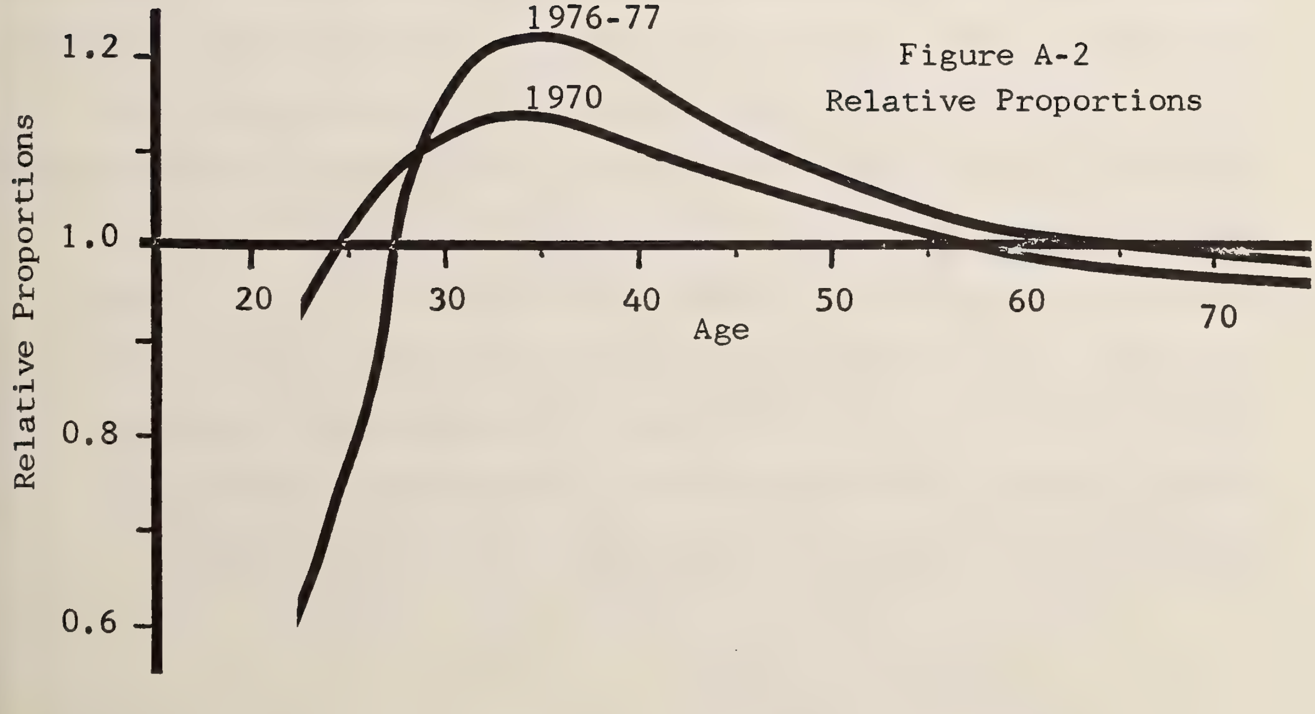
*"Suburban" means in this table "not in central city" and there-includes exurbs.

**Fewer than 10,000 households estimated, based on fewer than 200 households sampled.

Source: Adapted from Annual Housing Survey: 1976, Houston, Texas, H-170-76-49 (Issued August 1978).

Figures A-1 and A-2
ABSOLUTE AND RELATIVE SUBURBAN PARTITION PROPORTIONS
Married Males, Houston SMSA





couples. Table A-1 (last two columns) and Figure A-2 show that married couples and children are generally overrepresented (relative partition proportion exceeds 1.0) in the suburbs - the exceptions being young and elderly couples - and that persons in every other HHS category are <u>underrepresented</u> in the suburbs (and therefore necessarily overrepresented in the central city). More importantly, these data show that this type of stratification has been increasing since 1970 - that is, the population characteristics of the two sectors are <u>diverging.</u>

It is reasonable to suppose that this divergence in characteristics which occurred in the first 6 or 7 years of the previous decade has continued in the past few years. (Note that this supposition does not apply to dispersion of <u>numbers</u> of people - we <u>know</u> that this process has continued, as evidenced by residential construction data and as will soon be known with some precision from the 1980 provisional census "head count" data. Rather, this supposition addresses the <u>types</u> of people who are moving to the suburbs as its housing stock expands.) That is, we posit that the type of migration which has occurred in the past few years is generally similar to that which occurred during the previous 6 or 7 years. We express this analytically by assuming that the 1976-77 curve for relative partition proportions must be intermediate between the 1970 and the yet-to-be-determined 1980 curve. Note that this formulation avoids explicit mention of migration and of cohort size. Further, by dealing exclusively with <u>proportions</u> (which are, of course,

simply regional shares), we avoid the necessity of a post-calculation adjustment to require consistency with regional-level data.

APPENDIX B

CALCULATION OF HYPOTHETICAL DEMAND: SECTORAL PARTITION PROPORTIONS

The first of the five major steps in the dispersion model is the calculation of a hypothetical demand for residential location space by sector.

This is done by a hypothetical allocation of the region's projected population by age, sex, and household status (HHS) among the sectors. The chief analytical tool in this calculation is the sectoral partition proportions. These proportions express the distribution by sector of each age-sex-HHS group. For example, given the number of women age 30-34 who are family heads in the entire region, a certain proportion will live in the core, a certain proportion in the outer suburbs, etc., and the sum of these proportions will obviously be unity. (It is to be noted that the sectoral partition proportions do not sum to unity within a sector by age, sex, and HHS; rather, they sum to unity over all sectors within a single age-sex-HHS group.)

Previous work by one of the associates of INTERCHANGE shows that since 1950 the sectoral partition proportions for age-sex groups have been fairly stable on an age-specific basis for persons younger than middle aged and also fairly stable on a birth-cohort-specific basis for persons middle-aged and over. The major change over time has been a gradual increase of the suburban partition proportions (at the expense of the city proportions) for all age-sex groups. This means that, if the suburban partition

proportions for either sex are plotted by age, the curve will be rising gradually over time for the younger age groups while maintaining its approximate shape; and it means that the corresponding plot by year of birth will approximately keep its shape for the earliest (oldest) cohorts, while also gradually rising over time.

To calculate the hypothetical demand for residential location by sector, values for the sectoral partition proportions will be assigned in accordance with the observed approximate stability (in the sense described above) and trends in the proportions. These will then be multiplied by the population in each respective age-sex-HHS classification. The result is essentially an expected number of people in each classification by sector, absent constraints; this is interpreted as the hypothetical demand.

The essence of the dispersion model is that when the existing large values of the suburban partition proportions for persons in their thirties are multiplied by the large numbers of people who are or will be entering this age range during the 1980s, a very large surge in potential demand for suburban residential location materializes.

Appendix A provides examples of the Suburban Partition Proportions in the Houston SMSA for selected age and HHS categories in 1970 and 1976-77.

APPENDIX C

DATA AVAILABILITY AND SOURCES

Demographic and housing data comprise the bulk of the data required for this research. In general, there is a super-abundance of data at appropriate levels of detail, mainly through federal sources, especially the Bureau of the Census. Further, we have chosen metropolitan areas which have good supplementary data sources for small areas on construction estimates, housing values, and population. Therefore we expect no significant problems in data acquisition. The INTERCHANGE associates are skilled and experienced in combining census data and other data to produce high-quality approximations of data items which are not published in the precise form desired.

Among the key data and sources are:

- The provisional "head count" data from the 1980 Census by census tract, namely (1) Total population, (2) Group-quarters population, (3) Total number of housing units, (4) Number of vacant housing units. (Note that household population is derived as the difference of the first two, the number of households is derived as the difference of the latter two, and average household size is the quotient of these two differences.) These four numbers will be sent to the Division Offices in July 1980 for verification by local officials and will be informally available at

that time. No other 1980 Census data of value to this research will be available until late 1981. (Processing of the Census questionnaires for characteristics data will not even begin until the official release of the total population by political jurisdiction on April 1, 1981, as required by law.)

- The 1970 Census, which provides by far the most extensive detail available in characteristics of population, households, and housing at various geographic levels via summary tape, public use samples, and numerous publications (including the Subject Reports, which provide the greatest detail of all, especially at the U.S. level).

- Previous Decennial Censuses, which provide a basis for judging which characteristics are relatively stable and which are subject to large changes.

- The 1975 Survey of Income and Education (SIE), which provides fairly detailed income characteristics of population and household by state. It is notable for providing distributional information (not simply means and medians) by population and household characteristics which is post-1970, geographically comprehensive, and based on a large sample.

- The Annual Housing Survey (AHS), which is conducted in major SMSAs triennially on a rotating basis beginning in 1974, provides considerable detail on charac-

teristics of households and housing (and, indirectly, of population). The AHS is available for the Boston, Houston, Seattle, and Tacoma SMSAs.

In general, AHS provides more cross tabulations of household characteristics versus housing characteristics than the decennial censuses, although the detail in the housing characteristics and household characteristics separately is of course less extensive in AHS. Among the characteristics available are journey-to-work data.

The principal limitations of AHS are (1) that it is based on a small sample, viz. either 5,000 or 15,000 housing units (we have chosen regions for which the larger sample was taken, except for Tacoma), and (2) the only geographic breakdown is "in central city" versus "not in central city." Moreover, in the Boston region the Boston SMSA per se encompasses only about two-thirds of the region of interest - a deficiency which should be corrected when the Office of Federal Statistical Policy and Standards implements the new Metropolitan Statistical Area scheme.

o Selected publications in the Current Population Reports (known as CPS) Series, including especially the Annual March reports <u>Marital Status and Living Arrangements</u> and <u>Household and Family Characteristics</u> (both in the P-20 series) and various estimates and

projections of population and households for the U.S. and for states. These will be used with caution due to unduly arbitrary assumptions in the projections and estimates and apparent biases in the household samples.

o Selected publications in the Current Housing Reports series, which provides current information on housing construction by amount, type, and value at various levels of geography. These must be heavily supplemented by local sources.

In the Boston region building permit data by type are maintained by the state Department of Community Affairs at the MCD level, while in Houston and Seattle they are maintained at the tract level by the Chamber of Commerce and the regional COG, respectively. While employed by the Office of State Planning, one of the INTERCHANGE associates, Dr. Sanders, prepared the only extant longitudinal summary and analysis of building permit data by type at the MCD level in Massachusetts. Data on housing value are maintained by Banker and Tradesman and the Real Estate Transfer Directory in the Boston region and by the Real Estate Monitor Corporation in Seattle. A longitudinal analysis of housing values by tract in Houston from 1970 to 1975 was recently published.*

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*Barton A. Smith and Robert Ohsfeldt, "Housing Price Inflation in Houston: 1970 to 1976," Policy Studies Journal, Vol. 8, No. 2, pp. 257-276, 1979.

Data on building lot availability and cost are maintained by the Advance Mortgage Corporation for a number of the large metropolitan areas in the U.S., including our three regions.

- The Continuous Work History Sample (CWHS) of the Bureau of Economic Analysis, which provides longitudinal data for several samples of individuals on a large number of selected characteristics. This is a key source of migration data at the inter-metropolitan level. Its main weakness is poor coverage of young adults who have not yet entered the work force.

  The basic documentation of the CWHS data is <u>Regional Work Force Characteristics and Migration Data: A Handbook on the Social Security Continuous Work History and Its Application</u> (December 1976). Dr. Sanders was a member of the National Advisory Committee for the preparation of this document.

- <u>Residence and Migration of College Students: Basic State-to-State Matrix Tables</u>, which provides details on post-secondary students by state of residence and state of origin. Published irregularly by the Office of Education of Department of Health, Education and Welfare, most recently for Fall 1976 and Fall 1968. Data from this source are very detailed by type of school, course of study, and grade level, but have

no age detail. Age detail must therefore be imputed from the 1970 Census and CPS reports on college students.

- Vital statistics data, which are published annually in Vital Statistics of the United States and monthly in Vital Statistics Report by the National Center for Health Statistics (NCHS). NCHS is also a principal source of research reports on vital rates and of unpublished vital rates data. The NCHS data on divorce and marriage rates and on mortality by marital status, age, and sex - much of which are unpublished - are essential in this research for the analysis of household headship behavior. A limitation is that divorce data time series is comparatively short due to low state participation prior to 1965. (Note that most NCHS data are more conveniently obtained indirectly, via the Census Bureau, who has combined the "raw" NCHS data with other relevant files - notably age-specific population coverage - to produce the standard series on mortality, fertility, and population projections.)

- Transportation data are not nearly as uniformly available as housing data. It is prepared and collected and published differently in each region. The exception is the travel-to-work data in the Annual Housing Surveys. These data will be used for summary purposes in our project. Transportation network and usage data

will be assembled from various MPO documents in each region; most notably the TSM and TIP documents. These are prepared or updated annually.

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APPENDIX E

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. Concepts pertaining to gathering, analyzing and displaying key regional demographic and housing data were introduced as a means for timely reporting of forthcoming demographic changes in the U.S., their implications for metropolitan residential patterns and growth policy, and in turn the implications for transportation policy.

Systems Dynamics Model

STUDY DESIGN REPORT

FOR AN

INNOVATIVE APPROACH TO UNDERSTANDING

THE INTERACTIONS OF TRANSPORTATION

AND SOCIETY

PART I: STUDY DESIGN

PART II: WORK SCHEDULE

Prepared for the:

DOT/Transportation System Center
Kendall Square, Cambridge, MA 02142

under contract #DTRS-57-80-C-00033

February 28, 1980

DAA Enterprises, Inc.

675 Massachusetts Avenue

Cambridge, MA 02139

TABLE OF CONTENTS

PART I: STUDY DESIGN

* Section not included

Pages 1 through 12 have been deleted.

SECTION 2. DETAILS OF THE PROPOSED METROPOLITAN SIMULATION MODEL, METSIM

2.1 Explanation of causal diagrams

Section 2 of this report concerns the explanation of the dynamic hypothesis underlying the metropolitan simulation model, METSIM. The purpose of a causal diagram is to show how the elements of a system's structure relate to one another. The text of Section 2 will present how each sector of the METSIM model functions and how the various sectors relate to one another. A causal diagram includes entities which are linked by arrows. The theory of a causal diagram is that the entity at the tail of any one arrow causes a positive or negative change in the entity at the head of the arrow. Figure 2 is a detailed representation of the problem definition for this study which was described above in Section 1.

As shown in Figure 2, the increased location of upper socio-economic class people in the suburbs causes an increase in the need for commuter transportation. Since an increase in the entity at the tail of this connecting arrow causes an increase in the entity in the head of the arrow there is a positive sign noted at that head of that arrow. An increase in the need for transportation eventually results in increased transportation capacity linking the suburbs and the city. Increased transportation capacity results in a reduction in congestion and a reduction in commuting time, which results in the further location of upper socio-economic class people in the suburbs. Thus, a change in one element of the system has worked its way around a feedback loop which results in the future change of the original system element.

Other important feedback loops in this system concern the location of both upper socio-economic class people and businesses in the suburbs, which results in the aging and eventual deterioration

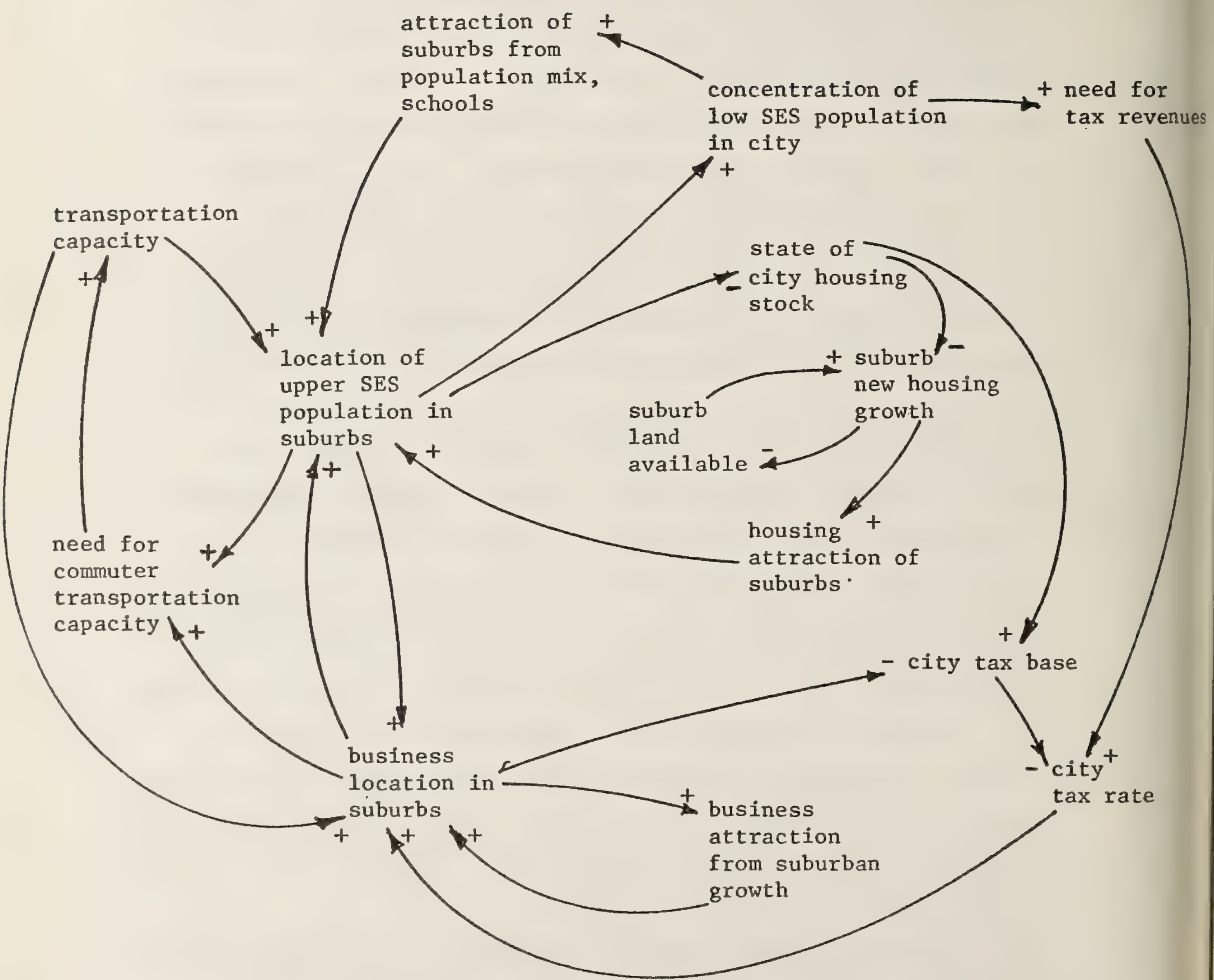


FIGURE 2: Detailed Problem Definition

of the city housing and building stock, since more and more of the new buildings are being built in the suburbs. The concentration of lower socio-economic class people in the inner city increases. The need for welfare, urban services and urban infrastructure increases. The increasing need for city social services, coupled with the static or declining urban tax base combine to cause the city tax rate to increase relative to that of the suburbs. Increased tax rates are a factor causing both people and businesses to locate outside the center city.

Other feedback loops in Figure 2 concern the effect of decreased land availability on new housing and business growth in the suburbs as well as the effects of socio-economic population mix in the residential location decision. The discussion which follows in the remainder of Section 2 concerns a more detailed representation of this basic system structure.

2.2 Metropolitan Business Growth and Zonal New Business Distribution

The metropolitan area is composed of a number of zones which are composed of a number of clusters. A cluster is the first level of aggregation in METSIM and represents one or more cities or towns. Figure 3 shows the causal relations involved in the construction of new business structures in the metropolitan area and how that construction is distributed among the various zones. The business attractiveness of each zone in the region is a function of five conditions within the zone which include the labor supply, the tax rate, the available land, the growth rate of existing business in the zone and the overall adequacy of the transportation system. The attractiveness of each zone coupled with the population of each zone is used to compute an overall weighted attraction of the metropolitan region. The overall attraction of the region determines whether the region wins a greater or

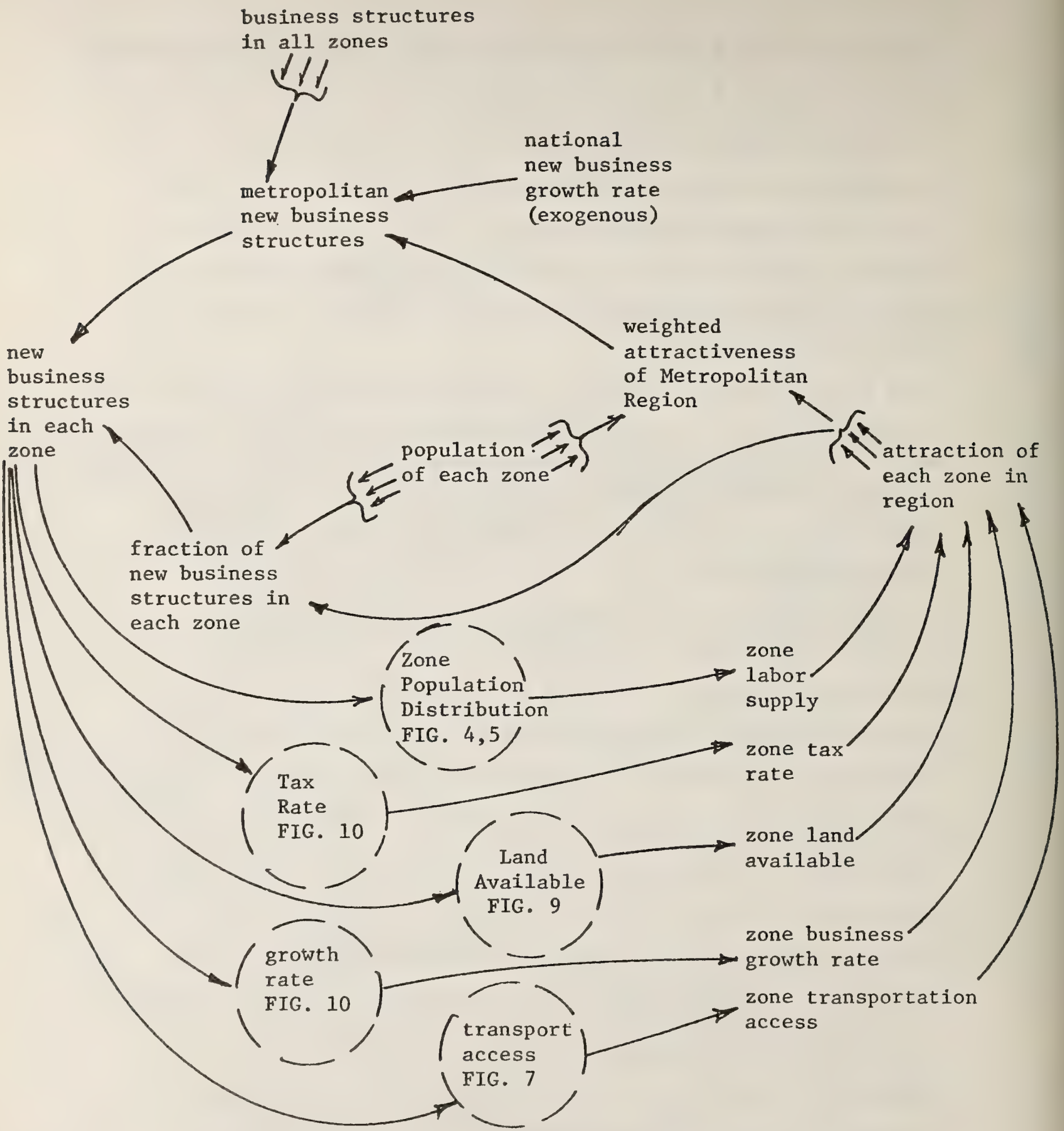


FIGURE 3: Metropolitan Business Growth and Zone Business Distribution

lesser share of the average national new business growth.

The national average new business growth reflects overall conditions in the national economy and is one of the two principal exogenous inputs to the METSIM model. Actual new business activity in the region is thus a function of the percentage national growth rate, the present size of the metropolitan area in terms of business activity and the weighted endogenous attraction of the region. The actual new business activity in any one zone is simply a function of the ratio of the attractiveness of that zone relative to the other zones in the region. The deashed circles which link the actual new business activity to the five elements of attractiveness represent other sectors of the model. Note, that each time a model sector appears within a dashed circle, the figure number of the causal diagram is given as a reference.

Thus the function of this sector is to determine the overall rate of metropolitan business growth and to distribute that growth, along with intraregional business movement, among the various zones that make up the region.

2.3 Metropolitan Population

METSIM simulates the migration of people into and out of the metropolitan region as well as the shifts of residential location within the region. These population movements are governed by the attractiveness of the different parts of the region in a heirarchical fashion similar to the allocation of business activity.

The function of the metropolitan population sector is to determine the overall rates of migration into and out of the region, and to allocate the migrating population among the zones and clusters. Figure 4 shows how the in-migration rate is determined, and how the new migrants are allocated among the zones. The determination of the out-migration rate is similar.

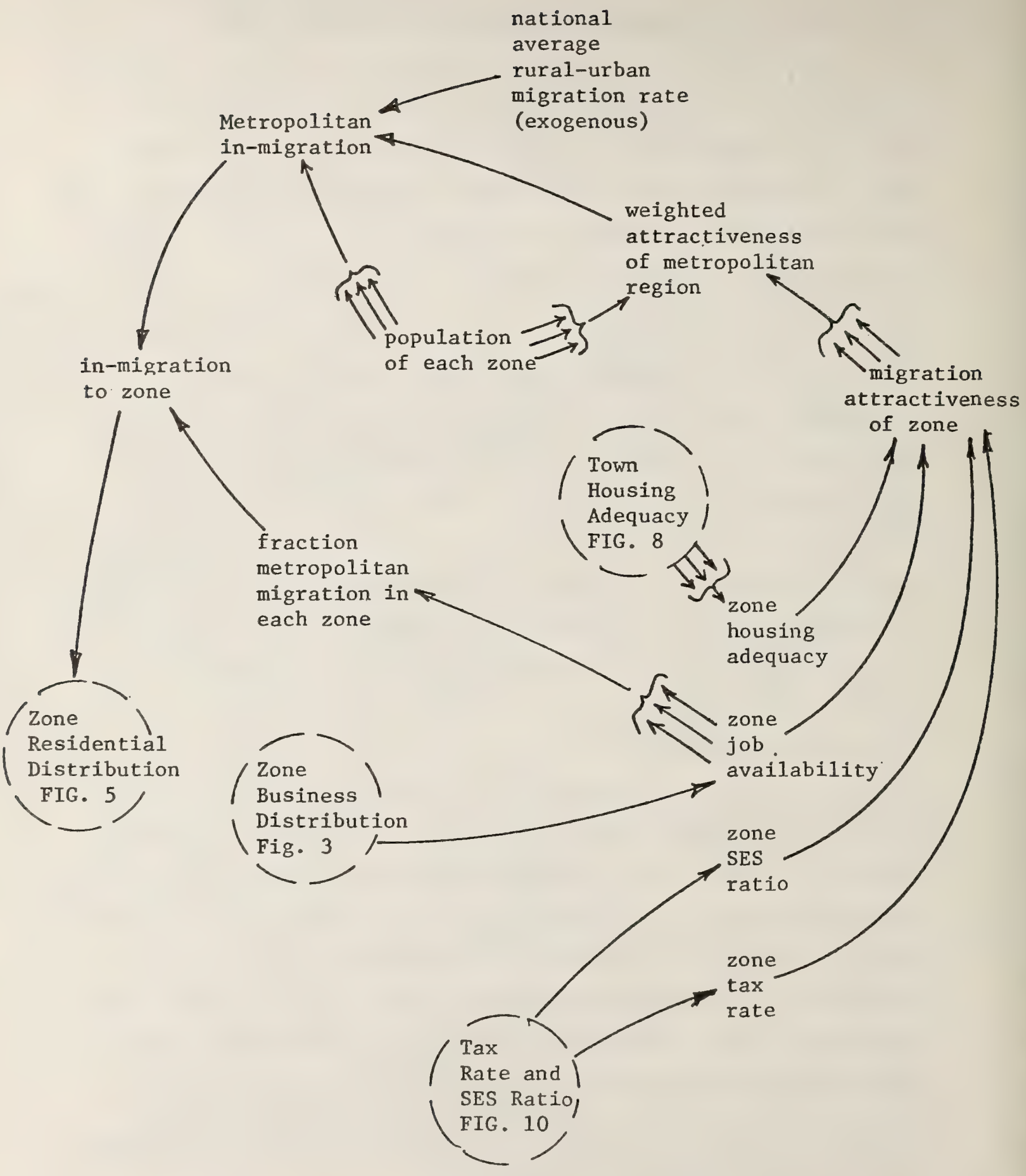


FIGURE 4: Metropolitan Population Migration and Zone Workforce Distribution

The migration attractiveness of a particular zone is a function of four parameters which include the housing adequacy, job availability, the socio-economic mix of the zone, and the tax rate. The migration attractiveness of each zone, when weighted by its overall population level, is used to calculate an overall attractiveness of the metropolitan region. This endogenous attractiveness, is combined with the exogenous normal rate of rural-to-urban migration, to determine the actual rate of in-migration to the region. Note, that the normal rate of in-migration to the region is the other principal exogenous input to the METSIM model. The people working within any particular zone are assumed to be only a function of the job availability within that zone. Thus the actual number of new workers in each particular zone is a function of the total in-migration to the region and the rate of job availability in that zone relative to the other zones within the region. Again note that the dashed circles represent other sectors of the METSIM model.

2.4 Zonal Residential Distribution

The METSIM model assumes that people make residential location decisions in a hierachical manner. As shown in Figure 4, people first choose the zone in which they will work based upon job availability in the zone relative to other zones in the metropolitan region. After they have chosen a work zone, people may choose to reside within the work zone or in any contiguous zone. People who choose to reside in a zone contiguous to the zone in which they work are called commuters. If people reside in the same zone in which they work they are called non-commuters.

The factors which influence an individual's choice of residential zone, after he has already chosen a work zone, are shown in Figure 5. In this figure, "zone i" is used to indicate an individual's work zone and "zone j" is used to inducate a zone in which he could live, which is either the <u>same zone</u> or a contiguous zone. The fraction of zone i workforce living in zone j is determined by the population weighted residential attractiveness

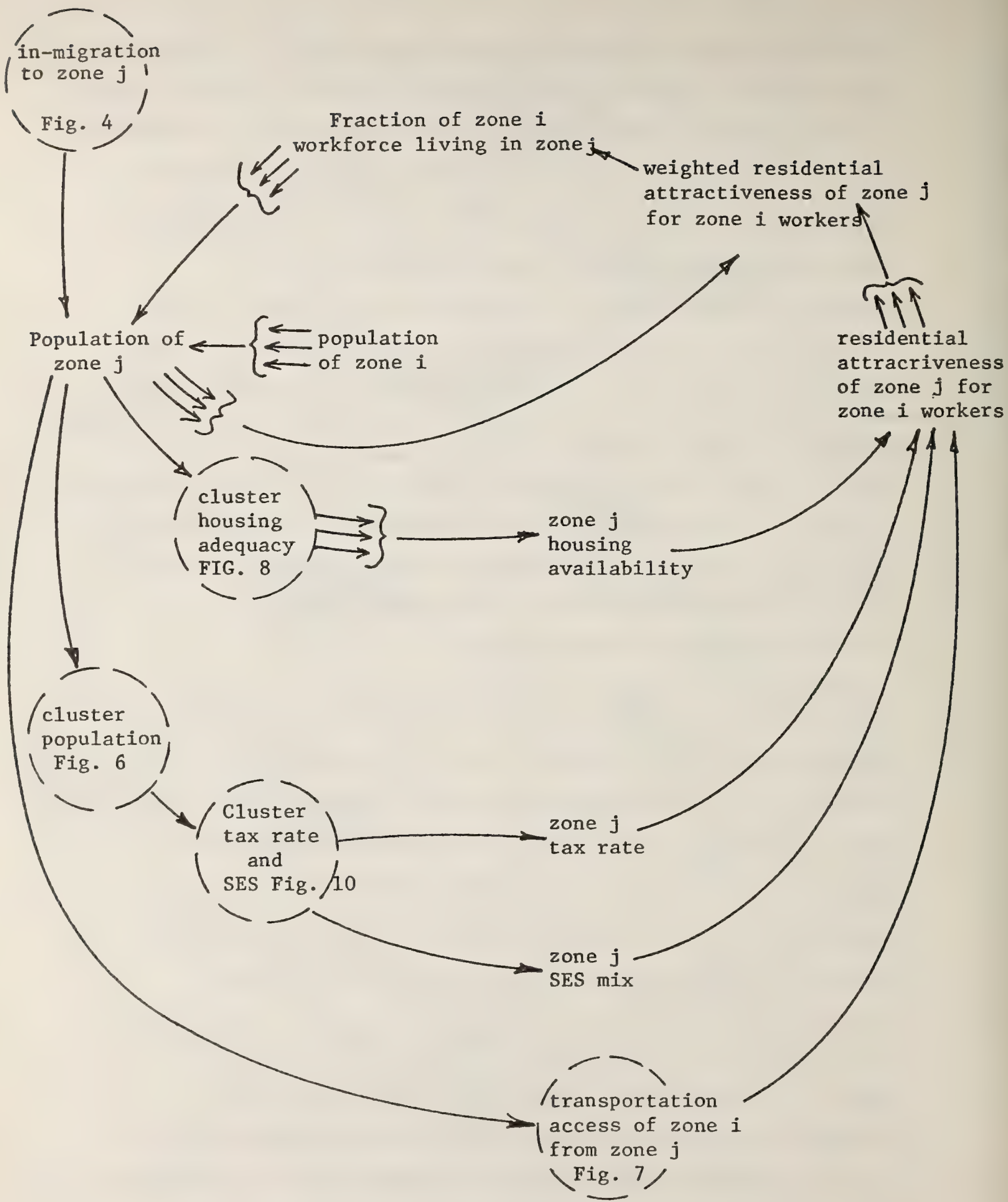


FIGURE 5: Zonal Residential Distribution Sector

of zone j for zone i workers. The residential attractiveness of zone j for zone i workers is a function of four factors: the housing availability in zone j, the tax rate in zone j, the SES ratio in zone j and the transportation access of zone i from zone j. These factors are computed in other sectors of the model on the basis of zone and cluster populations. The population of zone j is calculated by taking into account the workers from each zone who live in zone j as well as the in-migration into zone j.

The structure in Figure 5 is replicated for each socio-economic class. Note also that this structure makes possible the caluclation of the number of commuters between each pair of contiguous zones in the metropolitan region.

2.5 Town Residential Distribution

Figure 6 shows the structure used in METSIM to distribute residents in each zone among the various town clusters making up the zone. The residential attraction of each cluster is a function of three parameters which include the housing adequacy in the cluster, the tax rate in the cluster, and the socio-economic composition of the cluster. The fraction of zonal residents living in a particular town cluster is determined by the population weighted residential attractiveness of the cluster. The population of the cluster is calculated by taking into account the zonal population, the fraction of the population in the cluster and the number of new residents in the cluster. As shown by the dashed circles in Figure 6, the populations of each town cluster are inputs to the housing sector, the tax rate sector, and the socio-economic mix sector.

2.6 Transportation: Zone and Regional Feedbacks

For the purpose of describing this sector, let us define zone i and zone j as contiguous zones and the commuter traffic from

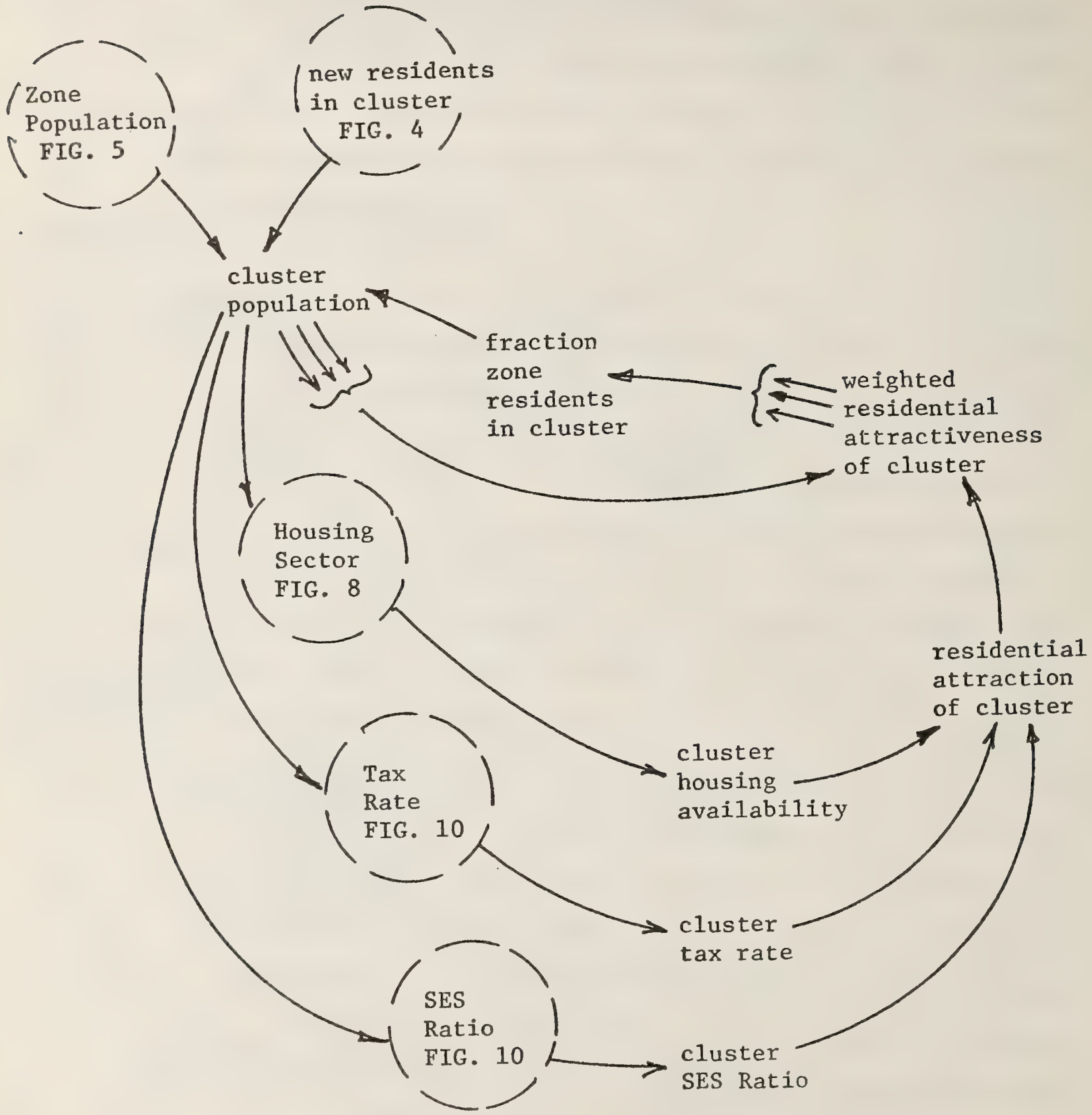


FIGURE 6: Town Residential Distribution

zone i to zone j to take place along the ij artery. Figure 7 shows that the total number of commuters on the artery between zones i and j is determined in the zonal residential distribution sector in Figure 5. The total numbers of auto and transit commuters are based on the total number of commuters and the fraction of auto commuters. The fraction of commuters choosing the automobile is determined by the relative attractiveness of mass transit versus auto commuting along the particular ij artery. The attractiveness of a particular mode is in turn a function of the congestion of the mode for a particular artery and the cost of the mode of transportation. Congestion is determined by the capacity of the artery and the total number of commuters using the mode on ij artery.

It is assumed that the capacity of each mode of transportation can be increased over time as the congestion on the artery is perceived in the light of public transportation policy. The highway and transit construction delays respond to transportation policy in addition to the influence of the land occupancy fraction in zones i and j.

Attractiveness of each mode of transportation along the ij artery is weighted by the modal capacities and used, along with attractiveness of all the other arteries of zones i and j, to calculate the transport access of zones i and j. Thus the transportation access of a particular zone is a function of the cost and congestion of each mode of transportation along each artery leading between that zone and all continguous zones. This measure of transportation access is then used to compute the attractiveness resulting from metropolitan business growth as shown in Figure 3 and the attractiveness of commuter zones relative to workforce zones as shown in Figure 5.

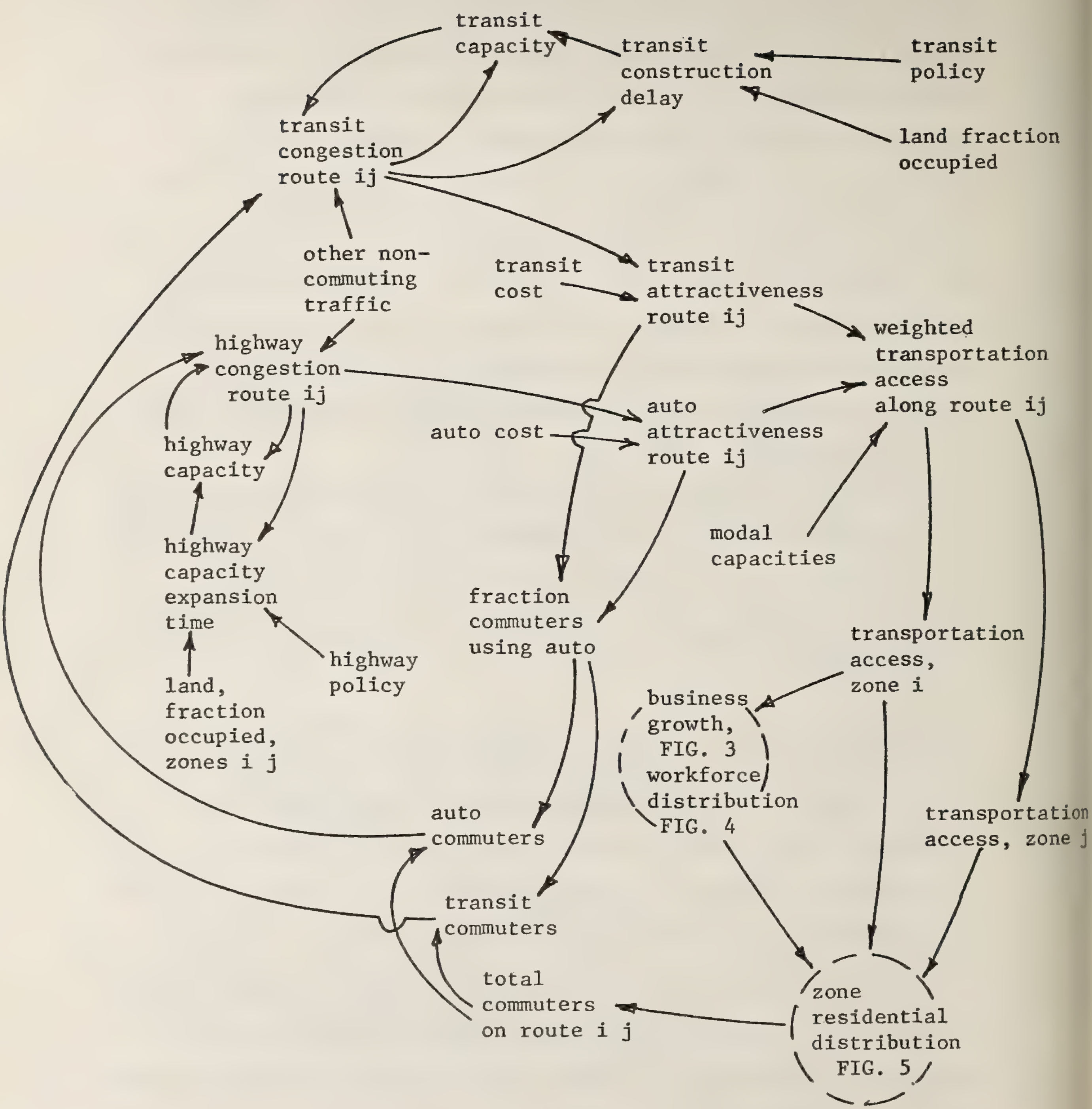


FIGURE 7: Zone and Regional Transportation Feedbacks

Note that the capacity on artery ij can be made different from the capacity on artery ji because of differences in transit schedules in the two directions or because of such devices as differential tolls and lanes which change directions on highways.

This transportation sector can be further elaborated by adding non-commuter through traffic and non-commuter intrazonal traffic as inputs to modal demand, and therefore transit and automobile congestion, along particular arteries.

2.7 Housing: Cluster, Zone and Regional Feedbacks

Housing adequacy in a town cluster, as shown in Figure 8, is determined by the total housing demand and the present stock of housing. Shortages of housing increase the new housing construction rate, which results in increases in the housing stock. The housing stock is decreased by being demolished, in which case it leaves the system altogether, or by trickling down from upper socio-economic class housing to lower socio-economic class housing. As more housing is built the availability of open land for new housing decreases, which in turn decreases the new house construction rate.

Figure 8 shows that housing adequacy determines the housing attraction of a particular cluster and that this housing attraction is used to determine the fraction of new migrants residing in that cluster, the fraction of new metropolitan migrants residing in a particular zone, and the overall rate of population in-migration to the metropolitan area. All of these intrasectoral feedbacks are shown in dotted circles in Figure 8.

2.8 Land Availability

Land is considered to be a physical constraint to growth of both busineses and residential construction in the METSIM model. Figure 9 shows that as the land occupied by business structures and

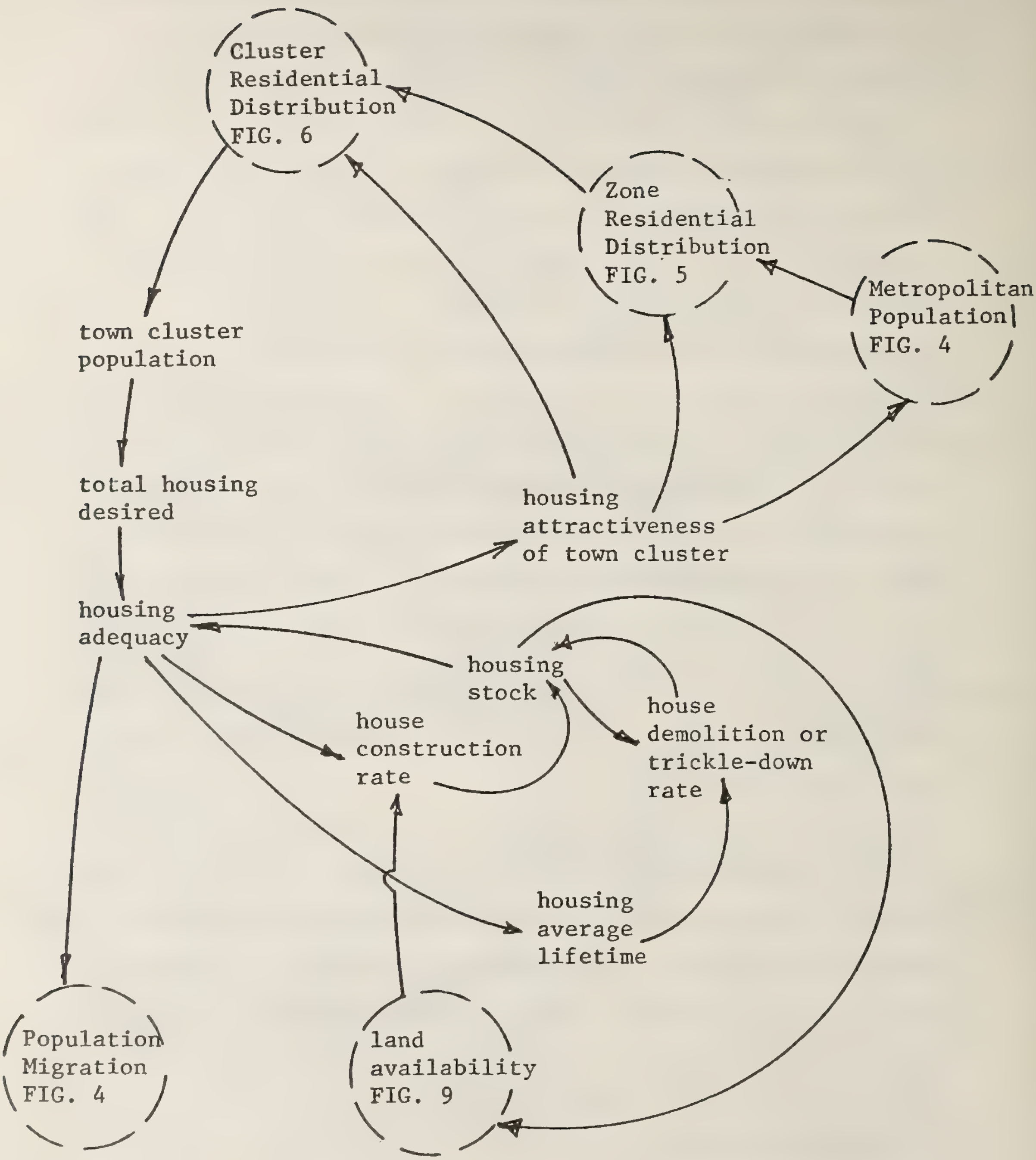


FIGURE 8: Metropolitan, Zone, and Town Cluster Housing Feedbacks

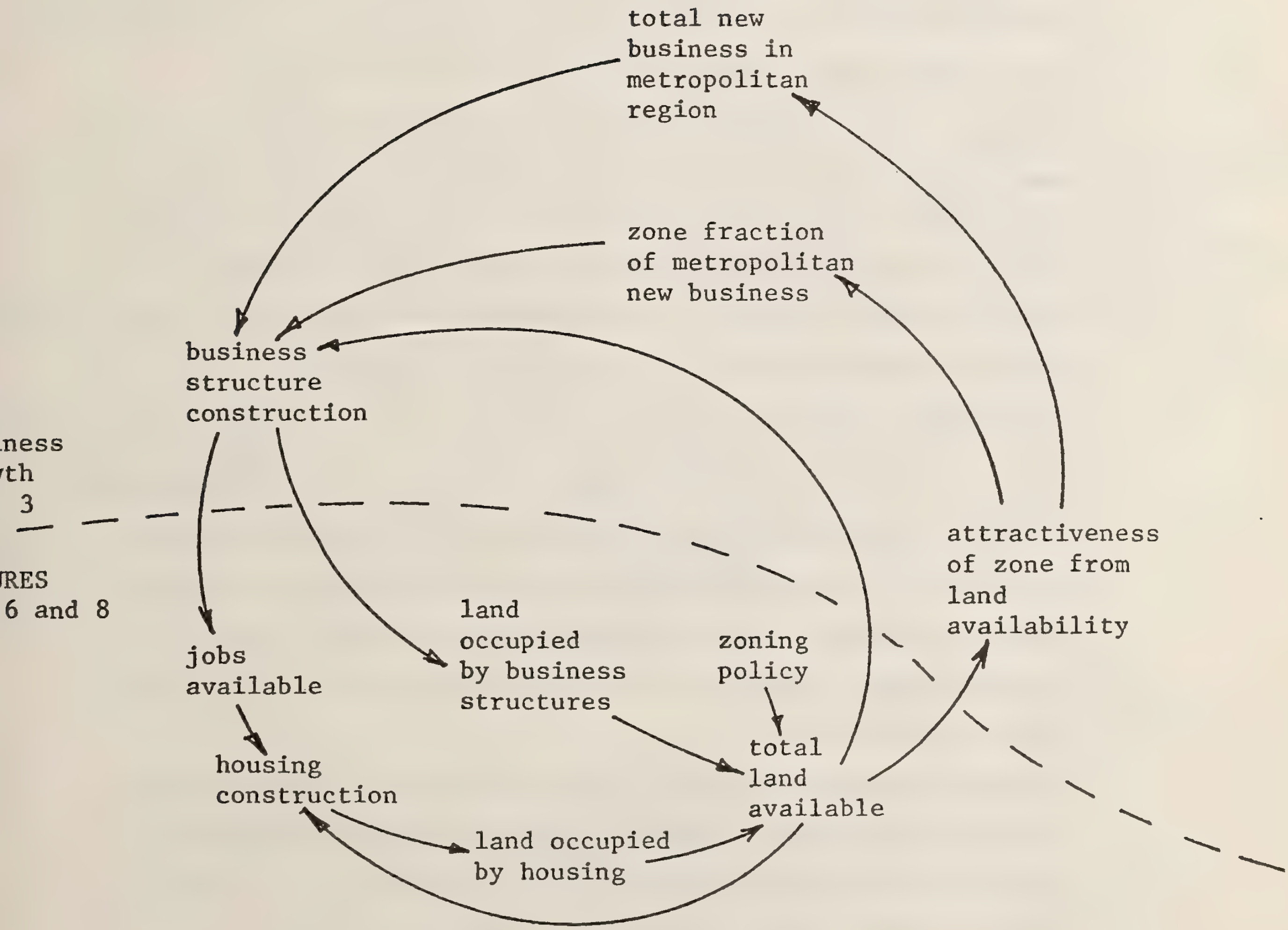


FIGURE 9: Land Availability

and the land occupied by housing increases, the land available in the zone decreases, which in turn affects the attractiveness of the zone for new business construction. As new business construction decreases, new jobs available in the zone decrease and this in turn affects the new housing construction in the zone. All of these dynamics take place in the context of the current zoning laws. Typically, as the land becomes totally occupied at a particular density, the zoning laws are changed to allow greater intensities of use. Such changes in the zoning laws can be included in the simulation model to allow density increases in particular towns and zones within the model as the urban area evolves.

2.9 Socio-Economic Status, Tax Rate and Growth Rate

The socio-economic mix of the population is calculated for each town cluster within each zone in the metropolitan area. The socio-economic mix of the population is simply the ratio of the upper class population to the total population. As shown in Figure 10, each town cluster will include two population classes and two housing classes. Each zone will include two classes of business structures. Socio-economic status of the population will be determined by a quantifiable characteristic such as income, education, or occupation. As shown in Figure 10, both populations are increased by net migration rate and net reproductive rate. In addition, the lower socio-economic class of population may experience upward mobility by taking on the income, education, or occupational characteristics of the individuals in the upper socio-economic class.

Each town cluster includes two different housing types. Upper socio-economic class individuals tend to occupy upper socio-economic class housing, whereas lower socio-economic class people tend to occupy lower socio-economic housing. Both housing classes

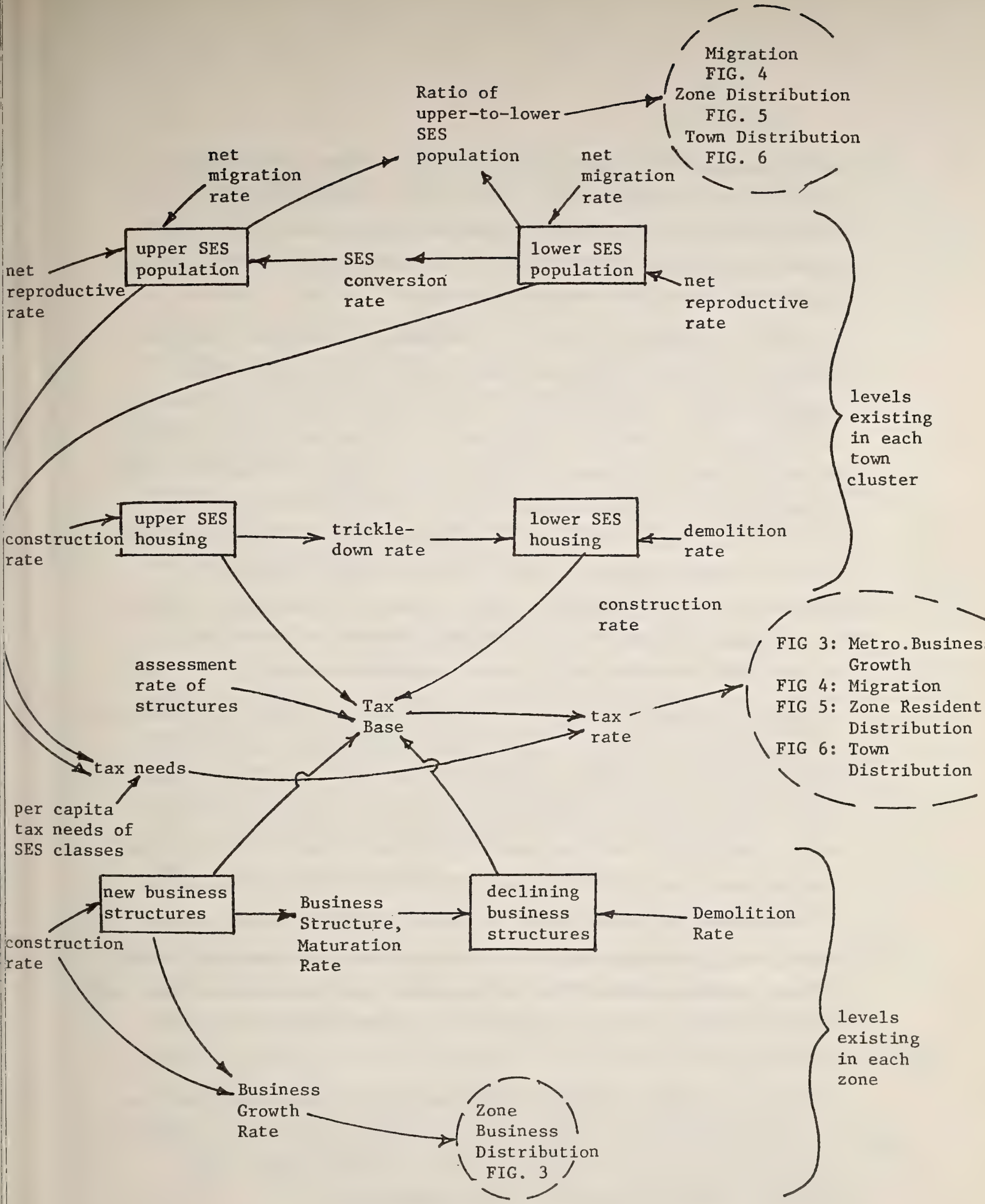


FIGURE 10: Socio-Economic Status, Tax Rate and Business Growth Rate

may be increased by construction rates and lower socio-economic class housing is decreased by the housing demolition rate. Upper socio-economic housing is converted into lower socio-economic class housing as it depreciates. Both classes of housing contribute to the tax base of the zone.

Each zone contains two classes of business structures. Business structures include factories, commercial, office, and retail establishments. Associated with each class of business structure are a number of jobs for each class of population. As the physical business structure depreciates, the architecture and the technology become obsolete. The business itself either becomes obsolete or it moves to a newer structure. Business structures are increased by new business structure construction rate and decreased by business structure maturation rate. Declining business structures are increased by the business structure maturation rate and decreased by the business structure demolition rate.

The rate of economic growth of the zone within the metropolitan region is determined by the new business structure construction rate relative to the overall level of new business structures in the zone. Both types of business structures contribute to the tax base according to their assessed valuation. Thus the tax base of the metropolitan region is a function of all the business and housing structures existing in each zone of the region.

The tax needs of each zone are a function of the number of people in each socio-economic class in the zone. The tax needs of the zone relative to the tax base are used to determine the tax rate of the zone.

The structure shown in Figure 10, therefore, illustrates how the relative proportions of different classes of population, housing, and business structures feed back into the residential and business location decisions in the METSIM model.

2.10 Zone Definitions and Interzone Commuters

Figure 11 illustrates how commuters and non-commuters are defined relative to the zones of a metropolitan region for the purposes of the METSIM model. The actual zones and town clusters within the zones will be determined in the beginning of the project and will be based upon present commuting patterns and the development of those patterns over the evolutionary history of the city. The zones in Figure 11 were drawn to include all the towns included in the standard metropolitan statistical area. The spatial boundary of the METSIM model will include all of these above towns, augmented by a number of additional towns, if necessary, for the sake of transportation route consistency.

As the example in Figure 11 shows, the commuters who work in Zone 2 are all those individuals who work in Zone 2 but who reside in any of the contiguous zones 8, 3, or 1. The commuters along the Zone 2-8 interface are found by adding the commuters who live in Zone 8 and work in Zone 2 to commuters who live in Zone 2 and work in Zone 8. The total residents of Zone 2 are found by adding the non-commuters who both live and work in Zone 2 to the commuters who live in Zone 2 and work in Zone 8, Zone 3, and Zone 1.

2.11 The Metropolitan Region System Boundary

The metropolitan region selected for the first application of the METSIM model will correspond to the standard metropolitan statistical area of Boston, shown in Figure 12. This area is large enough to encompass the full range of evolutionary forces associated with the growth and decline of the central city and the spread of suburbanization from cities contiguous to the Boston central city to cities and towns progressively further away from the central city. This area is small enough, however, that the problem of collecting data or model parameterization should not be unweildy and the number of individual

Key:

non-commuter = R_i , i = Resident zone
commuter = C_{ij} , i = Resident zone
j = working zone

Zone 2 Example:

-contiguous zones are 8, 3, 1
-total residents in zone 2 = $R_2 + C_{28} + C_{23} + C_{21}$
-commuters on zone 8 and 2 interface (Routes 95,93,3) = $C_{82} + C_{28}$
commuters on zone 3 and 2 interface(128 and others)=$C_{23}+C_{32}$
commuters on zone 1 and 2 interface(Routes 2,93,3 etc) = $C_{21}+C_{12}$

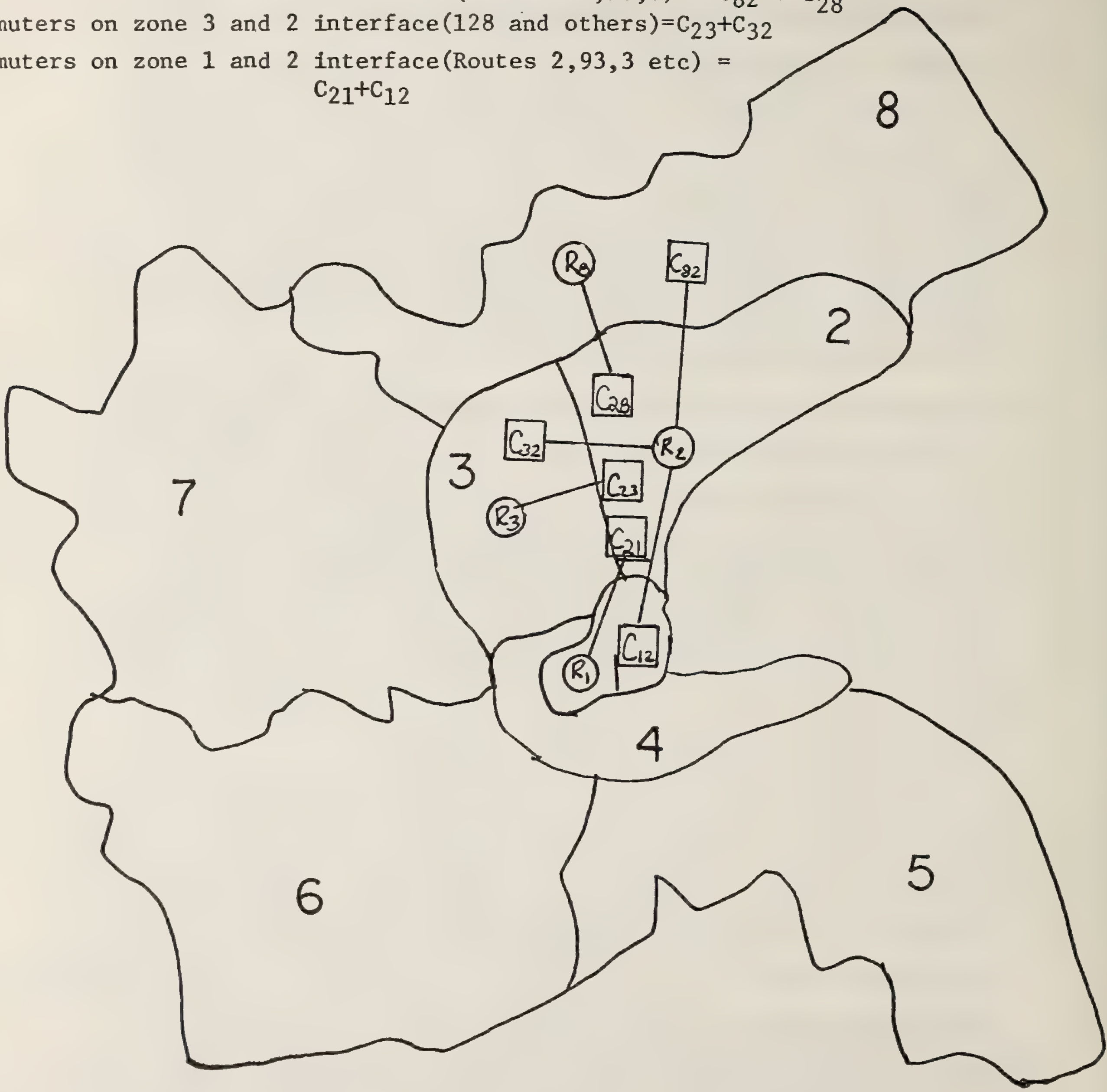
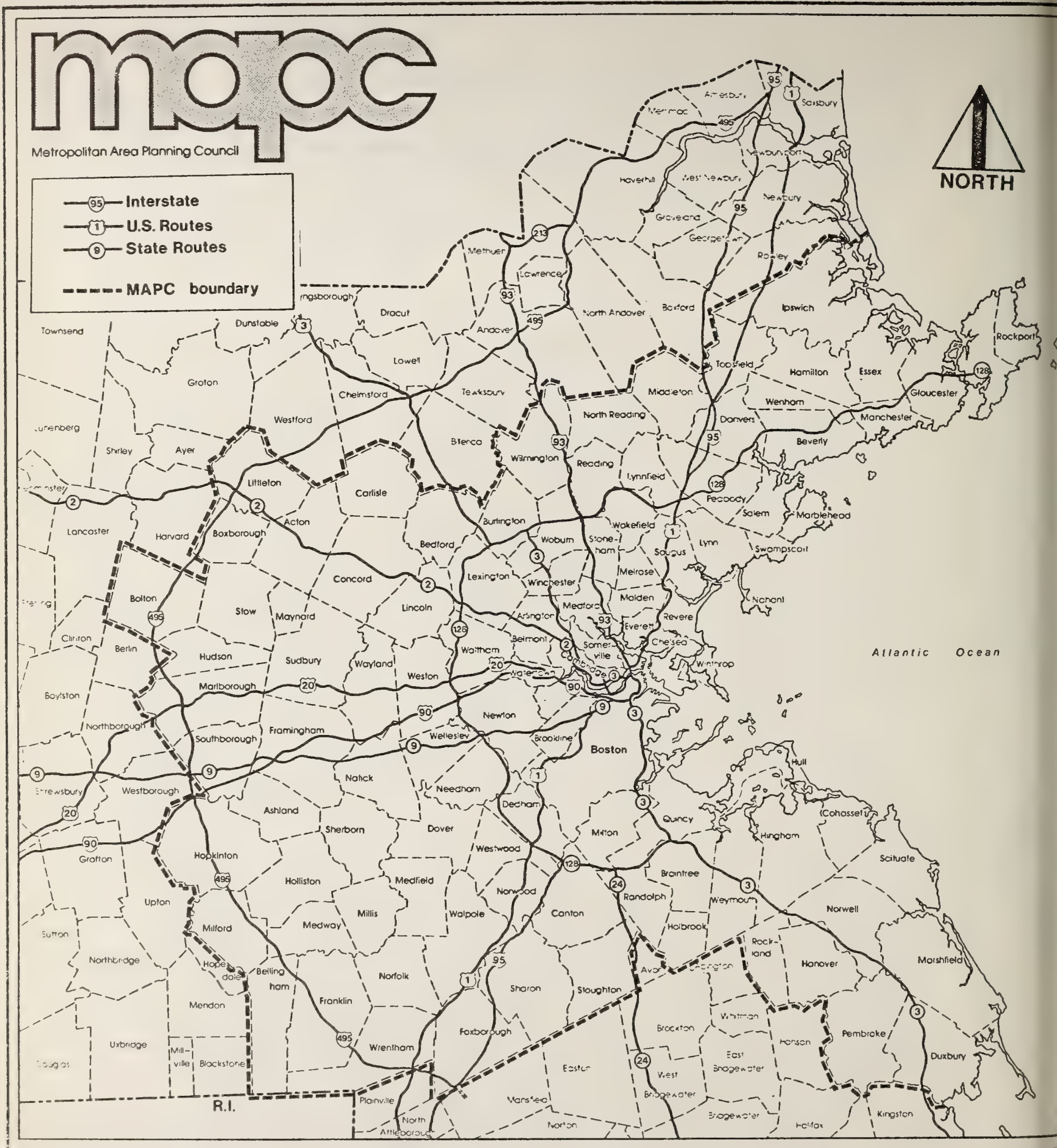


FIGURE 11: Definition of Zones and Inter-Zone Commuters

spatial entities will not render the simulation intractable. Furthermore, and most importantly, a consistent data set which spans both demographic, fiscal and transportation entities exists for this area.

FIGURE 12: The Metropolitan Region Defined as the Boston Metropolitan Statistical Area



SECTION 3. UTILITY OF THE MODEL FOR POLICY ANALYSIS

3.1 Transportation Policy

The METSIM model is capable of addressing a wide variety of metropolitan-wide transportation policy issues. Foremost among these is the classical issue of suburban access and its effect on the regional evolution of the metropolitan area. By adjusting the transportation cost and capacity policy parameters in the METSIM model, it is possible to simulate different suburban access policies and, therefore, to make a qualitative estimate of the role of transportation in the spatial growth of the city and the rate at which suburban areas have developed. It will be possible to experiment with future programs for increased suburban access relative to policies of ignoring or decreasing future suburban access.

Related to the question of suburban access is the question of modal split, and the extension of mass transit services further and further into the metropolitan suburban ring. In particular the long term locational impact on population mix and industrial mix of responding to congestion along interzonal arteries by building mass transit capacity instead of highway capacity can be examined with the model.

A third issue, which is becoming increasingly important with rising fuel prices, is the effect of modal cost on commuting. Whereas many studies have undertaken to determine the effect of cost on demand for particular modes of transportation, the METSIM model is capable of integrating this demand information into a much broader urban framework so that the long term demographic, economic and fiscal impacts of modal costs can be estimated. It is clear that these impacts take many years to filter through the complex interactions that make up the urban system and thus a long term

evolutionary model is required to analyze them. Of particular interest would be an examination of the impact of significantly higher real gasoline prices, on the order of five times the present price, over the next generation. Would this result in a revitalization of the inner city, or in the development of a number of high density activity centres ringing the central city? What effect do transportation mode policies have on this expected evolutionary pattern?

An important issue for urban policy makers continues to be the effect of transportation access on business growth. Although there is not much empirical evidence that transportation capacity has a short term effect on the location of business and industries, it seems obvious that the overall facility with which goods and people can be transported in the metropolitan region would have a significant effect on the location of new industries. Assuming this is the case, the long term effect of transportation policy on economic growth can be examined.

The policy analysis applications of the METSIM model will include, but will not necessarily be limited to, these transportation-related policies.

3.2 Urban Policy

The urban policies that may be simulated with the METSIM model cover the range of problem areas outlined in the problem definition (Section 1.2.2) of this report. The model is capable of simulating policies to address physical, fiscal, economic, and demographic problems. Urban policy applications with the model will include, but will not necessarily be limited to, the following examples.

The most obvious program to deal with the physical decay of the inner city is to demolish old structures and renovate declining areas. Programs which would result in a decreased number of declining housing and business structures can be easily tested in the model

by increasing the demolition rate to simulate the implementation of condemnation programs, tax relief for demolishing old buildings, or community renewal. The associated population would then relocate. The effect on the model would be to increase the amount of land available, for both housing and businesses, and thus relax the constraint to further growth.

Policies which address the fiscal problems of the city can be simulated in a variety of ways. Tax relief can be simulated by supplying the needed tax revenues from an exogenous source, or the burden of the tax can be shifted from one population group to another or from one industry class to another by adjusting the assessments on the various types of houses and buildings. Finally, the tax burden can be adjusted by increasing the efficiency or decreasing the overall level of services provided.

There are a number of ways to simulate the implementation of various economic programs in the METSIM model. A primary economic objective of urban policy planners is to stimulate the development of business, and therefore jobs, in the inner city. This can be done in the model by adjusting any one of the parameters which affects the attractiveness for a new business location. Thus, zoning policies can be simulated which would increase the concentration of business activities.

Policies which seek to address the problem of changing demographic structure in the inner city include job training, or the subsidization of various classes of housing structures. The effect of a job training program can be simulated by increasing the rate of socio-economic conversion from the lower socio-economic class population to the upper socio-economic class population. Simulating an increase in the construction rate of either upper income class or lower income class housing would result in an increase in the population group that demands that class of housing.

3.3 Synergistic Policy Sets

Synergistic policy sets are groups of combined transportation and urban policies. The policy sets are implemented in an effort to accomplish a broad long term goal for the metropolitan region. The examination of synergistic policy sets with the METSIM model will include, but will not necessarily be limited to, the following types of scenarios.

A city-oriented scenario may include programs such as restricting access of commuters to the central city by increasing the cost of commuting through tolls and parking fees and using the revenues to increase the attractiveness of the inner city to business locations. Thus the taxes on businesses could be reduced and the taxes on commuters increased proportionately. The issue with this policy set is whether commuting cost and business opportunity would be sufficient to motivate the commuters to relocate their residences in the inner city, thereby stimulating the housing market and increasing the tax base. It may be that such a policy set would simply accelerate the flight of businesses from the center city due to decreased access. The corollary issue is what will happen to the economies of the suburbs if this policy set is in fact successful. The result of this policy simulation will depend on the relative strength of the wide range of attractiveness coefficients and time constants for physical change that have been assumed for the METSIM model.

A second synergistic policy set is a social welfare scenario which includes a number of programs primarily directed at the lower income population. In addition to programs to increase the capacity and lower the cost of mass transit, low cost housing would be constructed and job training programs would be implemented. The primary issue with this policy set will be whether, after completing job training programs, the mass transit

system results in increased access to employment opportunities, and whether in fact the population will make use of this transportation mode.

A third policy set could be constructed from suburb-oriented policies. The effect of improved access between suburban zones in conjunction with policies to promote industry location in the suburbs could be simulated. The primary issue to be resolved with this simulation is whether the development of suburban growth centers has a long term detrimental effect on the economy of the inner city.

The above examples are described for the purpose of showing the potential of the METSIM model. Since the model is rich in policy analysis possibilities, the combinations of different policies which can be simulated is enormous.

3.4 Specific Audiences

The clientele for the METSIM model will include any public or private planner who is interested in the long term evolutionary impact of the above described policies and scenarios. In particular we would expect that individuals in the Department of Transportation, the Department of Housing and Urban Development, in metropolitan planning councils, in regional planning authorities, and in state and city transportation and planning departments would be able to utilize the model.

The best use of the model would be to simulate transportation and related urban development policies to determine their long term impacts on a wide variety of parameters. This information should then be used to evaluate city, state, and federal transportation and urban development goals. Thus the model is best used in an iterative fashion to give policy makers the possibility of implementing programs which are consistent with their long term

goals. Ideally, the programs from the housing and transportation department at the city, state and federal levels should be coordinated to reinforce one another instead of working at cross purposes. Such mutually reinforcing policies can only be designed with the aid of a policy model which includes all of the sectors of interest.

SECTION 4: DATA AVAILABILITY AND ADEQUACY

4.1 Parameterization of System Variables

It is important to clearly define the major system variables in such a manner that both present and historical data can be found to quantify them. The most important system variables which we plan to track through time for the historical and validation simulation runs (see Section 5) are the population classes, the housing structures and the businesses structures (see Section 2.9 and Figure 10). A minor amount of statistical analysis may be required to quantify these variables. The issues involved in defining some of these major system variables are discussed below.

For purposes of the model, the social class of the population will be defined in terms of occupation. In addition, we will be using two social classes in the model, upper and lower. Upper class will be defined as those families where the head of the household holds a skilled job or higher, and lower class will be defined as those families where the head of the household holds a semi-skilled job or lower. When we say higher or lower we are using the occupational classification as defined by U.S. Bureau of Census, Dictionary of Occupational Classifications. For ease of analysis the definition of social class in the present case is limited to a single variable, that of occupation.

Limitation of a general description of social class to a single variable is somewhat at variance with common usage. More generally, socio-economic status (SES) is seen as composed as a number of variables, each contributing to the overall status position. Very often analysts use a combination of income, education and occupation to derive this general SES position.

It is important to note that the use of an individual's occupation as a proxy for social class position seems to have merit given the small changes in an occupation's status rank over time. From the

first study of occupational ranking in the 1920's,[1] to the present day, most occupational positions have remained virtually the same. the status ascribed to occupations tends to be the same regardless of the population doing the ranking, and in fact, seems quite stable even cross-culturally (where equivalence of occupation can be unambiguously demonstrated).[2] We acknowledge all the problems inherent in attempting to derive social class position based on a single variable. However, given the long historical (and in some senses futurological) time span with which we must deal, this appears to be the only appropriate approach.

For the housing variable, information will be based on the age and cost of the housing in which people live. Housing prices are determined to a certain extent by inflationary pressures, and thus not truly comparable over time. One approach would be to standardize housing prices in 1960 dollars by use of a price index and use this to determine changes in housing classes over time. Information for the housing sector will be obtained insofar as possible from the United States Census of Housing conducted every ten years.

4.2 Sources of Data

The primary sources of data for this study will be printed reports available at various places in the Boston region. Our intention is to rely on the available printed materials, and if they do not contain sufficient information for our purposes, we will then utilize computerized data bases.

The Metropolitan Area Planning Council maintains an extensive library of information about the towns within the planning region. This data includes information on population (from the U.S. Census), tax

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[1] See G. S. Counts, "The Social Status of Occupations" School Review, 33(1925): 16-27.

[2] Alex Inlekes and Peter H. Rossi, "National Comparisons of Occupational Prestige" American Journal of Sociology, 61(1956): 329-339; and J. Michael Armer, "Intersociety and Intrasociety Correlations of Occupational Prestige" American Journal of Sociology 74(1968): 28-36.

information, transportation information for each town and finally, a small amount of information about manufacturing and commerce in the towns. We plan to use the information gathered by the Central Transportation Planning Staff of the Metropolitan Area Planning Council to augment the more general data available from the MAPC. We also expect to use the printed reports available at the U.S. Bureau of the Census regional office in Boston. A large amount of information about manufacturing and commerce is available at the Baker Library of the Harvard Business School and it is expected that this information will be used to supplement that from MAPC. In the case of the printed data (as well as the computerized data noted below), while some minor aggregation of the data may be necessary, statistical analysis will not constitute a major part of this approach.

Should the printed information prove to be insufficient, we will plan to access some of the computerized data bases that are currently available in the Boston area. In particular, we plan to use the information from the 1970 Census of Population and Housing, Fourth Count Summary Tape Files and the information from the Dun and Bradstreet Financial Profile Screening Service.

The following represent some of the printed sources from which we will draw empirical information to be used in the construction and validation of the Metropolitan Simulation Model.

Commonwealth of Massachusetts

Annual Report of Vital Statistics, Department of Public Health.

Massachusetts Cities and Towns, Employment - Unemployment, Monthly Report. Division of Employment Security.

Metropolitan Area Planning Council

1978 Overall Economic Development Program, 1978-1979 Program Update, Boston SMSA (Metropolitan Area Planning Council: Boston, MA).

United Community Services

1972 Social Facts by Census Tracts. From the United States Census, 1970. Volume I: Acton to Medway, Volume II: Melrose to Woburn. (United Community Services: Boston, MA).

U.S. Bureau of the Census

1970a Characteristics of the Population, Volume I, Part 23: Massachusetts. <u>1970 Census of Population</u>.

1970b Employment Profiles of Selected Low-Income Areas, Boston, MA. <u>1970 Census of Population and Housing</u>, PHC(3)-25.

1970c Housing Characteristics for States, Cities, and Countries, Volume I, Part 23: Massachusetts, <u>1970 Census of Housing</u>.

1977 <u>Censuses of Businesses</u>

Specific sources for each of the variables of the METSIM model are given in Table 1.

The METSIM model requires a significant amount of "behavioral data" which indicates, for example, the relative importance of all the various attractiveness parameters for businesses when they decide to relocate. Most of this data has not been recorded by town or city, but exists in a number of empirical studies concerned with industrial and residential location and urban evolution, both in Boston and in other cities in the United States.

It is clear that the relationships from one region to the next are not exactly the same, but they should provide rough analogs. The analogic relationship would provide us a better feel for what the situation is in Boston than our guesses. DAA has assembled an extensive bibliography of empirical research on urban job and residential location, urban evolution and urban transportation. Some of the more useful references for this behavioral data are listed following Table 1.

TABLE 1

DATA SOURCES FOR THE METSIM MODEL

Type of Information	Source
1. Population by Town or Zone	
Size - Total number	Census[1]
Family Size	Census - MAPC[2]
Birth Rate	State Health Department[3]
Death Rate	State Health Department
Percentage Commuters Across Zone	CTPS[4]
Unemployment Rate	Dept. of Employment Security[5]
Number of Workers Per Household	Census
Intergenerational Mobility	Census
Number of Persons Per Housing Unit	Census
In-Migration to Area	Census - MAPC
Out-Migration from Area	Census - MAPC
2. Housing by Town or Zone	
Average Age of House	Census
Unit Area Per Housing Unit	Census
Total Number of Housing Units	Census or MAPC
3. Industrial by Town or Zone	
Available Jobs	D & B[6]
Ages of Business Structures	D & B
Area (ft^2) of Business Structures	D & B
Age of Business	D & B
Total Number of Business Structures	D & B
Construction Jobs Available	MAPC
Construction delay	D & B
4. Transportation by Town or Zone	
Average Commuter Trip Length in Miles	CTPS
Average Commuter Trip Length in Minutes	CTPS
Commuter/Non-Commuter Trips per capita	CTPS
Capacity of Interzonal Transportation	CTPS
Destination of all Trips by Mass Transit vs auto	CTPS
5. Land Use by Town or Zone	
Land Fraction Allocated to Various Uses	MAPC
Zoning Regulations	MAPC
Average Lot Size Per Residential Structure	MAPC

TABLE 1 (continued)

Type of Information	Source
6. Fiscal by Town or Zone	
Government Expenditures per capita	MAPC
Assessed Value of Housing and Business Structures	MAPC
Tax Collections per capita	MAPC

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[1]U.S. Bureau of the Census. 1970 Census of Population and Housing.

[2]Metropolitan Area Planning Council, Commonwealth of Massachusetts.

[3]Commonwealth of Massachusetts, Department of Public Health.

[4]Commonwealth of Massachusetts, Central Transportation Planning Staff of the Metropolitan Area Planning Council.

[5]Division of Employment Security, Commonwealth of Massachusetts.

[6]Dun and Bradstreet, Financial Profiles Screening Service.

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1972 "Socioeconomic Status and Work - Residence Separation in Metropolitan American" Pacific Sociological Review 15(3)(July): 367-380.

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1977 "Empirical Deterministic Model of Industrial Location" Journal of Regional Science 17(3): 357-367.

Tobin, G. A.
1974 "Issues in Urban Transportation" Urban Affairs Quarterly 10(1): 102-110.

4.3 Role of the Advisory Group

One of the major advantages to the use of an advisory group of experts is that we will be able to go to these experts for guidance in areas in which data is not available.

The major problem involved in utilizing real data in model construction is that much of the data provided by the Bureau of the Census is not directly comparable to the sectors of the model as the model has been designed. There is no question that there will be gaps in the information and that some of the information, for example, on population or housing will not be directly comparable.

If, for example, the census data shows that some percentage of the population in a town is upper class and some is lower class, and if the census data shows that some housing in that same town is expensive and other housing is not, then we will be able to ask our advisory group for guidance on the relationship between the two variables, _if_ this is not obvious from the data itself.

Many of the relationships to be demonstrated in the model seem to be intuitively obvious, the problem of course being that they may not be empirically demonstratable. The fact that some relationships cannot be demonstrated empirically, however, should not keep us from attempting to build such a model. Where data is available clearly we will use it, where data is not available or is not directly comparable, we will rely on the collective intuitive guidance of the advisory group. Where empirical studies do exist, we plan to rely on the advice of the advisory group in determining the relevance of the various studies (mentioned above in Section 4.2).

SECTION 5: MODEL TESTING AND VALIDATION

5.1 Replication of Historical Behavior

The first step in testing the METSIM model will be to replicate the growth of the Boston metropolitan area. This should be done over a period of about 100 years so that it is possible to judge whether the model simulates the spatial spread of the suburban areas in the correct manner. The first task in this test then will be to collect sufficient historical data on transportation and population in all of the cities and towns within the system boundary for the last 100 years. The criterion to be used to judge whether the model passes this test will be whether the major state variables of the model are in qualitative agreement with the actual historical trends. The major variables which should agree with historical behavior over time are the various classes of population, housing and business structures, and the land occupancy ratio. The development of transportation capacity as well as commuting traffic along the major arteries between zones should also agree qualitatively with historical behavior. A judgment as to whether the model adequately simulates historical behavior will be made by the advisory group. The advisory group will also judge whether the match between the model behavior and historical behavior occurred for the correct reasons.

5.2 Sensitivity Testing

Extensive sensitivity testing will be done on the METSIM model. Variations of the model output relative to the "base run" simulation of historical behavior resulting from incremental changes in the model's parameters will be examined to determine the parameters to which the model is particularly sensitive, and to determine if the model is liable to produce erroneous output because of small uncertainties in the quantitative data. Particular attention will be given to the initial values of the major state variables and the model parameters which determine the gain around the positive

feedback loops such as the attractiveness coefficients. Next the METSIM policy parameters will be exercised to determine their impact on all of the major state variables. Particular attention will be given to describing the model sensitivity to the transportation sector by examining the behavior of the simulation with no feedbacks to the transportation sector relative to the behavior of the model when transportation access is assumed to be very important for the location of businesses and households.

Finally, a limited amount of sensitivity testing will be performed by varying groups of model parameters. Since there are a huge number of combinations of multiparameter sensitivity tests that could be performed, these tests will be organized into scenarios such as a "rapid suburbanization scenario" or a "minimal suburbanization scenario".

5.3 Robustness of Behavior Modes Under Parameter Uncertainty

The purpose of the robustness testing is to determine whether the behavior modes of the principle system variables change over time as a result of stochastic variation in the principle exogenous inputs to the model. Both the normal business growth and the normal population in-migration rate to the metropolitan region will be stochasticly varied about their normal values over the course of the base run simulation. Numerous runs of the simulation model will be made with different stochastic inputs, and an "envelope" will be drawn around the bounds of the model outputs. The criterion for robustness will be whether the model state variables continue to behave in the same manner as they did in the deterministic base run simulation, or whether, for example, a state variable which was monotonically increasing during the deterministic simulation oscillates or decreases during the stochastic simulation. These model tests would be very much like Monte Carlo simulations, except that the expected values of the state variables at a particular time in the future will not be calculated.

5.4 Validation of the Dynamic Hypothesis

A general qualitative criteria will be used to judge whether the metropolitan simulation model is "valid". The project advisory group will be asked to judge whether the model is useful for aiding in the understanding of transportation-society interactions. The advisory group will be asked in particular whether the model produces the correct behavior for the correct reasons. Although statistical tests could be performed on the model outputs relative to known historical data, these tests are no help in deciding whether the causal interactions which produced the model outputs are the same as those which produced the real behavior. Since the model is primarily intended as an aid in understanding the structural interactions between transportation and society, a comprehensive validation procedure which includes both quantitative model tests and judgments based on experience in the field of transportation and planning, such as those mentioned above, is the mose useful means of validating the model.

SECTION 6: DIFFICULT FEATURES AND ISSUES TO RESOLVE

6.1 Structural Issues

Several problems of model formulation will have to be resolved early in the project. Chief among these is the determination of the effect of transportation access on industrial location. Although it seems almost certain that industrial location must be influenced in the long term by transportation access, there seems to be little empirical support in the literature on this point. The resolution of this issue will primarily affect the attractiveness coefficient of transportation access for industrial location.

A second issue to be resolved is whether to include the cost of the various transportation modes as exogenous or endogenous parameters. To resolve this issue one must determine whether the model is sufficiently rich in causal determinants of mode cost so that cost may be modeled as an endogenous parameter, or whether it is sufficient to change modal cost exogenously to reflect the history of modal development.

The question of whether cost and congestion alone are adequate to determine the demand for mass transit will have to be addressed. The effects of other attributes of the mass transit system such as operating frequency, schedules, and specific routes could be simulated if these are of primary importance in the long term.

Another important issue to resolve is the extent to which environmental quality parameters such as open space, noise and pollution affect industrial and residential location. If a case can be made that one or more environmental quality parameters have had a significant impact on the evolution of the Boston metropolitan area over the last 100 years then these will have to be included in the simulation model structure.

6.2 Data Availability Issues

Issues involved in the acquisition of data and the parameterization of the system state variables have been discussed in detail in Section 4 of this study design. In summary, these issues have to do with the definition of industrial and housing classes and the correlation of population classes with both housing classes and industrial classes. Historical data on transportation, congestion and cost may be hard to acquire for the early years of the simulation.

6.3 Specific Transportation Issues

The advisory group will be consulted relative to other attributes of the transportation system that affect location of businesses and households besides the cost and the congestion of the various modes. There is a whole variety of attributes of transportation systems such as comfort, reliability, safety, noise, travel time, perception of convenience, speed, flexibility and freedom of use. The issue to be resolved, if in fact the use of a particular mode is judged to be sensitive to these attributes, will be whether these attributes can be endogenously produced by the model or whether it is necessary to add new model structure.

The extent to which non-commuting transportation demands have to be simulated should be decided at the beginning of the project. Such demands may have a significant effect on the congestion of the system during times of peak use and may have an effect on the cost of the system if cost is modeled as an endogenous parameter. Non-commuting transportation includes local trips within a zone and through-trips from one zone to another which are not a function of industrial location.

6.4 Method of Issue Resolution

In general, the means of coping with major issues such as the ones listed above will be recommended by a consensus of the project staff and the advisory group together. Such recommended solutions will

always be discussed in light of whether the resources needed to implement the solution are available within the project budget and time constraints.

SECTION 7: THE PROJECT ADVISORY GROUP

7.1 Purpose

One of the more innovative aspects of DAA's proposal is the use of a panel of experts who will advise us throughout the stages of the design of the metropolitan simulation model. The advisory group is composed of a number of recognized experts in their fields who will consult with DAA formulation of the model. In addition, the advisory group will be asked to aid in the resolution of the "structural issues" noted in Section 6. Once the model has been formulated, we will ask the advisory group to examine the model output and behavior in the light of their individual knowledge and experience. The advisory committee, then, will be involved in the entire model building process from conceptualization through testing and up to and including validation.

7.2 Mode of Operation

DAA anticipates utilizing the committee on at least three separate occasions for approximately two days on each occasion. The first meeting will be held shortly after the beginning of the contract when all of the members of our advisory committee will be brought together for a two-day orientation session. At this orientation session we will spend some time describing our systems dynamics paradgm, we will provide the committee members with the initial model formulation, the "dynamic hypothesis", and data on variables which we have already found. We will seek their inputs in the areas of data sources, the resolution of the issues noted in Section 6, and we will define the problem behavior mode we expect the model to simulate. The second meeting of the advisory committee will deal primarily with questions that may be raised as we reach the model testing stage. At this point, we will ask the advisory committee to critique the base run simulation as well as the sensitivity tests, and to define the most important policies

to simulate. The last meeting will be scheduled toward the end of the project. At this point we will have our advisory committee examine the output of the policy simulation to see how these compare to "real" situations. As in the previous two meetings, the behavior of the model will be critiqued in light of the basic mechanisms that produce the behavior. Validity judgements will be made based upon all of the previous simulation runs. The advisory group will be asked to provide guidance on potential audiences for the model and the relative priority of further applications.

We anticipate that the work of the committee will entail a great deal of give and take between themselves and the DAA staff. We anticipate that the group dynamic which will develop among the members of the advisory committee may, in itself, provide us with a fair amount of information about regional and urban development. As questions of causation are raised, as causal sequences are discussed and as developmental chains are examined, numerous ideas will be generated which DAA will then evaluate and decide how and if to include in the model itself.

7.3 Members

The members of the advisory committee are:

Professor Alan Altshuler, chairman of the Massachusetts Institute of Technology Political Science Department, and is a Professor in the Department of Urban Studies and Planning. From June 1971 to January 1975, Doctor Altshuler served as Secretary of Transportation and Construction for the Commonwealth of Massachusetts. Doctor Altshuler is well known in the field of Urban Transportation and has written extensively on the subject. A recent book, The Urban Transportation System: Politics and Policy Innovation (MIT Press, 1979) deals with the land use effects of urban transportation improvements.

Professor Jefferey Osleeb is an Associate Professor in the Department of Geography in Boston University. Professor Osleeb has extensive experience in the analysis of transportation and its effects on the spatial relationships in the urban area.

Professor Wilfred G. Marston is a Professor of Sociology and Urban Studies and Chairman of the Urban Studies Department at the University of Michigan-Flint. Professor Marston has published extensively on population and has also done a significant amount of work in the segregation of populations in residential areas. In addition, Professor Marston has extensive experience in the analysis of census data.

Professor Jerome Rothenberg is a Professor of Economics at the Massachusetts Institute of Technology. Professor Rothenberg's interests are in the area of urban economics and the effects of transportation on the economy of an urban region. Among his extensive publications in this area are: Transport and the Urban Environment and Readings in Urban Economics.

We have spoken to all of these above people and have obtained letters from them agreeing to serve on the project advisory group. These letters, along with their individual resumes are included in Appendix A.

DAA had identified an expert in urban politics who was asked to serve on the advisory group. Although he indicated interest in the project, the press of his current assignments prevented him from joining us. Since his decision, we have not had time to replace him, so have retained a position on the group for a similar person and are continuing the search.

SECTION 8: INNOVATIVE ASPECTS

8.1 The Community Analysis Model

The Community Analysis Model (CAM) was developed by the MIT program on Neighborhood and Regional Change. The stated purpose of this model is to accurately reproduce changes in the neighborhoods of a metropolitan area over the past decade and to project the characteristics of these neighborhoods five to ten years into the future. These projections are used for medium term planning for such items as municipal budgets, schools, and transportation. In particular, the CAM model fits into the conventional Urban Transportation Planning System of methodologies as a forecasting methodology for population densities, land use, and socio-economic mix. From these outputs, demand for transportation services and the modal split can be forecast. CAM is also appropriate for impact studies such as projecting the impact of a single specific project such as the construction of a transportation link, the location of a major business in a neighborhood, or the creation of significant open spaces.

The focus of the CAM model computation is the choice of location of residences and business establishments among the neighborhoods of a metropolitan area.

People are classified according to age, education and ethnic origins. Dwelling units are classified according to age, condition and whether they are owned or rented by their occupants. An individual's choice of residential neighborhood is a function of the population and dwelling mix of the different neighborhoods, as well as other neighborhood characteristics such as transportation time to work and quality of schools. The prospective migrants rate each neighborhood according to the neighborhood's characteristics relative to their own preferences and decide a probability of moving to each neighborhood based on this rating. This creates a demand for housing in each neighborhood, which

is compared to the number of neighborhood vacancies resulting from out-migration and new construction. A market clearing process then balances supply and demand for housing and determines the number of people of each type moving between each pair of neighborhoods.

The simulation of dwelling construction reflects the entrepreneurial nature of contractors. New dwellings are constructed on vacant land in neighborhoods with high demand for housing or in neighborhoods with a great deal of open space adjacent to rapidly growing neighborhoods.

A description of the transportation network and the number of people wanting to travel from one neighborhood to another are used to calculate congestion on eack link of the network. From this information trip times are calculated for each transportation link. The travel time between neighborhoods is then calculated by adding together travel time on links connecting the neighborhoods. These travel times are updated about every five years.

Business establishments in the CAM model are considered to be one of three types: commercial, office or industrial. Each neighborhood is classified into one of eight categories according to its appropriateness for location of each business type. For instance, the central business district is classified as appropriate for commercial and office establishments, but less appropriate for industrial establishments. Suburban residential neighborhoods are classed as inappropriate for all significant business activities. This classification of neighborhoods does not change throughout the course of the simulation.

The overall growth of employment for each business type in the metropolitan area is determined by an auxiliary model that distributes projected national economic growth among 300 regions of the country. This overall growth is in turn distributed among the neighborhoods of the metropolitan area. Changes in employment are caused by the "births and deaths" of firms, by the expansion or contraction of existing firms, or by the relocation of firms. New employment in a

given type of business is attracted primarily to those classes of neighborhoods that are appropriate for that type of business. The choice of neighborhood location for business classes is influenced by a number of factors. The appearance of new employment in a neighborhood is a function of the existing concentration of business establishments in that neighborhood as well as whether those establishments are the same type of industry as the prospective in-migrant. Other characteristics of a neighborhood that make it attractive to new business locations are the availability of land for development, and the accessibility of a neighborhood to surrounding areas.

8.2 Differences Between the Proposed DAA Metropolitan Simulation Model and the Community Analysis Model

8.2.1 Purpose

The fundamental difference between the METSIM model and the CAM model is that the METSIM model is constructed for the purpose of understanding the interactions between transportation and society, while the CAM model is constructed primarily for land use forecasting. The METSIM model is constructed from causal feedback loops which explain the relationships between the problem of transportation and some generic physical, economic, demographic and fiscal problems of metropolitan region. The METSIM model is therefore a model of the long term causative forces behind the evolution of Metropolitan areas. Since the objective of the Department of Transportation is to further the understanding of the interactions of transportation and society and the role of transportation policy, and not to predict specific land use details, the METSIM model is a more appropriate tool for the Department in this area.

8.2.2 Validation

The differences in model purpose are reflected in the techniques employed to validate the metropolitan simulation model and the CAM model. Since the METSIM model is proposed as an aid to

understanding long term transportation-societal interactions, the criteria for validating the model will be whether the model reproduces the historical behavior mode as well as whether this behavior occurs as a result of the correct causal forces interacting in the model. The criterion for validating the CAM land use forecasting model is simply whether the model reproduces the correct land use patterns for a short stretch of recent history, about 10 years.

8.2.3 Transportation Emphasis

The METSIM model places a much stronger emphasis on the evolution of the transportation system and on evaluating the effects of transportation policies than the CAM model. The capacities and modal splits of the various interzonal arteries are modeled as endogenous entities that can change as functions of other forces within the model in the metropolitan simulation model. Transportation enters the CAM model only to the extent that demand along inter-neighborhood networks is forecast. Capacity in the CAM model is modeled as an exogenous entity which changes every five years. There is no modal split in the CAM model. In addition to congestion along interzonal arteries, the METSIM model will determine modal split as a function of cost. The greater detail of the transportation sector in METSIM renders it more useful for long term transportation policy analysis than the CAM model. It must be noted, however, that the level of aggregation of the METSIM model will generally be greater than that of the CAM model and therefore the METSIM model will not generate transportation demand in as much detail with respect to individual routes as the CAM mode.

8.2.4 Fiscal Policy

The role if differential tax rates, tax liabilities stemming from commitments of municipal services, and the effect of the physical condition of the city on its tax base is central to the evolution

of a metropolitan area. Whereas the METSIM model encompasses all of these causal relations, there is no fiscal sector in the CAM model.

8.2.5 Regional Business Location

The location decisions of businesses in the METSIM model are endogenous functions of a range of factors which can be affected by simulated policies. Thus, the probability that a particular zone will attract businesses of a particular type can change over time in the METSIM model. In addition, there is a feedback between the conditions in the metropolitan area and the rate at which businesses are attracted to that area from the exogenous environment in the METSIM model. This is not so in the CAM model. In the CAM model, the condition of the metropolitan area has no direct effect on the overall number of businesses that locate there, but is entered exogenously only as an overall trend.

8.2.6 Time Horizon and Model Outputs

Many of the structural differences between the CAM model and the METSIM model are due to the fact that the METSIM model is a long term metropolitan evolutionary model whereas the CAM model is a short term land use forecasting model. The long term time horizon of the METSIM model requires that it contain feedback structures and requires that such sectors as the transportation sector have endogenous capacity changes and that the overall rate of growth of the metropolitan area be sensitive to conditions within the metropolitan area. The long term time horizon of the METSIM model was selected on the basis of the types of policies that were to be examined. Whereas the time horizon of the METSIM model is 150 years, comprising 100 years of past history and about 50 years of future policy analysis, the time horizon of the CAM model includes 10 years of past history and 5-10 years of projection.

The outputs of the METSIM model are necessarily more aggregated than the CAM model. Whereas the METSIM model will be able to simulate the qualitative impact of a wide range of policies for

a long term into the future, the CAM model is capable of simulating the short term impact of a more limited range of policies at a greater degree of detail.

8.3 Building on Previous Work

8.3.1 DAA's Experience in Generic Regional Models

In formulating the proposed METSIM model, DAA will draw heavily on its experience in using system dynamics as part of a long range planning project of the Seawater Desalination Agency of Saudi Arabia. System dynamics was used in that project to make forecasts of water and power demand for each area of the country for 25 years into the future. In terms of the complexity of disaggregate regional modeling, the use of real empirical data, and the utility of the model in the clients' decision-making structure, this Saudi Arabian model represented an advance in the state-of-the-art of system dynamics simulation.

The model itself was developed in the DYNAMO 3 language as a generic structure that incorporated all of the necessary feedback loops within a population cluster and between population clusters. Population clusters were aggregated into watershed regions and watershed regions were aggregated into socio-economic zones. Then, for each socio-economic zone to which the model was applied, the generic model was "expanded" to fit the geometry of the socio-economic zone so that the correct number of watershed regions and population clusters were replicated. The model parameters were evaluated to reflect the character of each cluster and each watershed area within the socio-economic zone.

The DAA approach to developing the metropolitan simulation model contains many features similar to the Saudi regional water and power project. Like the Saudi project, the METSIM model will be a generic model that incorporates the interactions within and among zones and town clusters of the metropolitan region.

This generic model will be capable of "expansion" to fit any geometry and characterize any metropolitan region of interest. The model will be capable of using electronically stored data where available, and the parameterization of the model will make use of a wealth of information of a qualitative nature about the past historical development trends. Thus, the proposed project will draw on DAA's experience in formulating and applying regional development models over the past five years.

8.3.2 Relationship to Other Urban Systems Models

The proposed metropolitan simulation model cannot be classed according to contemporary categories of urban models. The METSIM model can neither be called a land use model, a migration model, a location model, nor a transportation demand model since it incorporates some aspects of each one of these methodologies.

In the field of urban models, the most similar model to the proposed metropolitan simulation model is the urban dynamics model developed by Professor Jay Forrester at MIT during the early 1970's. While the urban dynamics model was based on feedback loops and incorporated many of the same elements to calculate attractiveness coefficients to the metropolitan region, there are several fundamental and important innovative aspects of the proposed metropolitan simulation model which sets it apart from the work done at MIT. The most important difference is that the proposed METSIM model is spatially disaggregated and will include a hierarchy of three different generic types of urban space, while the urban dynamics model simulated the growth and development of a city as a single spatial entity. The spatial and hierarchical structure of the METSIM model requires that a theory of intersectoral interaction be formulated which is lacking in the urban dynamics model.

The second most fundamental difference is that the proposed metropolitan simulation model is oriented towards explaining how transportation interacts with the growth and development of the metropolitan area, and therefore the METSIM model includes a detailed transportation sector, whereas the urban dynamics model had none.

The third fundamental difference is that the METSIM model will be designed to utilize real empirical data from identifiable metropolitan regions. This means that the validation of the METSIM model will be focused upon how well the model tracks real observable data, rather than on subjective interpretations of urban development.

SECTION 9: FUTURE APPLICATIONS BEYOND THE SCOPE OF THIS STUDY

9.1 Time Constraints of the Present Study

Given the time constraints of this study, the proposed scope of work is ambitious. The emphasis in the project will be on the formulation, testing, and validation of of a generic metropolitan simulation model rather than on extensive multi-city applications. Once the model has been tested and successfully applied to the Boston metropolitan area, the model may be extended to other metropolitan areas and regions as described in the following paragraphs.

9.2 Extensions to Other Metropolitan Areas

The first extension of the metropolitan simulation model will be to apply it to a metropolitan area which has experienced a significantly different growth and development pattern than the Boston area. A first candidate would be a newer midwestern or western city, for example, which has not had the history of mass transit development that the Boston area has had, and which has had a significantly different demographic history.

9.3 Extensions to Regional Analysis

Once the metropolitan simulation model has been successfully applied to a range of different cities to examine the role of transportation within the metropolitan area, the next step is to examine the role of transportation in regional development. In order to simulate a region, the zones of the metropolitan region, which have been described above, would become entire cities and transportation would take place between the cities. The town clusters, which make up the zones in the metropolitan model described above, would be redefined as zones in the regional model. Thus, by redefining the levels of aggregation, the metropolitan simulation model can be applied to the problem of intercity transportation development. The accomplishment of this

task involves the collection of data for each one of the cities involved, and is therefore too time consuming to be included in this project proposal.

9.4 Automation of Model Replication and Data Analysis

After experience has been gained in applying the METSIM model to a range of urban areas, the process of replicating the model can be automated by writing computer programs to expand the generic model code for however many zones and town clusters are to be included in a particular metropolitan area of interest. Beyond this, experience with sources and reliability of various data sets will allow the possibility of automating the retrieval and transformation of data where such data is available on magnetic tapes, or at least the analysis and incorporation of the data in the model.

9.5 Development of User Awareness

Concurrent with the application of the metropolitan simulation model to an increasing number of urban areas should be an effort to increase awareness of the model among federal, state and city urban transportation planners who are the intended model users. Seminars should be held in various parts of the country to increase awareness of the model's capabilities and to gather feedback from the potential users about their priorities. Such information could be used to further revise the model so that its utility and use would be increased.

SECTION 10: DOCUMENTATION

10.1 Contract Deliverables

The proposed study will include the production of flowcharts, model descriptions and simulation run plots and tables so that the model may be understood and the results replicated. These include:

- A system dynamics flowchart,
- A documented model listing,
- A technical description of each equation and data source,
- Base run results,
- Sensitivity test results tables,
- Policy run results tables,
- Scenario run plots,
- A summary of the comments and usggestions of the advisory group at each of the meetings, including a validation summary and their suggestions for potential audiences and future applications.

10.2 Documentation According to SSDP Standards

10.2.1

Because the SSDP documentation effort could consume an unreasonable portion of the funds allocated for follow-on research work, we recommend that it be done at a future time, if at all. A discussion of the SSDP documentation is presented here so that the Department of Transportation can decide whether to commit resources to it at a later date.

The purpose of the work described in this proposal is to develop and test an innovative approach to understanding the role of transportation in the long term growth of American Society. The focus of this work will be a computer model that dynamically simulates the interactions among the location of residences, the

location of businesses and transportation. This model will be developed in the DYNAMO language, and will be structured so that it can use electronically retrievable data to the greatest extent possible.

The aim of the task described below is to convert the model as developed by the end of the main project into a package suitable for inclusion in the Urban Transportation Planning System (UTPS) of the Urban Mass Transportation Administration (UMTA). This conversion will consist of two subtasks: 1) exec routine; 2) model translation.

The exec routine will enable the user to access the program and will enable some of the bookkeeping functions of UTPS. The model translation will convert the simulation model from DYNAMO to standard FORTRAN. These subtasks would proceed according to the heirarchical development specified in "Software Standards, Part I", UMTA Report No. UTP.40.73.3.1, August 1979.

10.2.2 Description of Work

10.2.2.1 Exec Routine

The exec routine will act as the interface between the user and the program. It will access the program and allow the user to reproduce the results in the model developed, and to perform other runs of the model such as policy alternatives, as desired. The exec routine will also perform the bookkeeping functions required by the SSDP standards. The development of the exec routine will be accompanied by the development of a user's manual.

10.2.2.2 Model Translation

The model translation task will consist of writing a program in FORTRAN that performs the same calculation

as the DYNAMO program that will be developed in the main part of this project. The principal issues in the translation will be to establish the correct order of calculation, the development of a table look-up routine, a parameter input routine and a flexible tabular output routine. The subtasks of model translation are described below according to the format presented in "Software Standards, Part 1".

General functional specifications. Factors that must be considered in establishing the computation order will be presented, and an algorithm for setting this order will be described. The table look-up and tabular output routines will be described.

Detailed technical specifications. The algorithm for establishing the computation order will be applied. The DO loop structure of the computation order will also be established by this algorithm. The algorithms for table look-up, parameter input and tabular output will be established.

Computer code. The model equations other than table look-up, parameter input and tabular output in FORTRAN will all be obtained from corresponding DYNAMO model equations by making minor revisions. The input, output and table look-up equations will follow from the technical specifications.

Test design and results. The FORTRAN program will be run against the DYNAMO program on a number of test problems already done in the main part of the project.

Pages 72 through 100 have been deleted.

PROJECT TASKS

Task	Description or Comments
PHASE I: formulation	
1. Define Zones	according to transportation criteria, for 100 years history
2. Define town clusters	according to transportation and residential criteria, for 100 years history
3. Write equations	in DYNAMO III
4. Advisory Meeting #1	plan and hold meeting review model, identify problem behavior mode, data sources needed, structural issues
5. Debug METSIM	add real data as available
6. Collect data	population,housing,business,transportation, inputs,collection analysis to define variables,aggregation to zone and cluster
7. Base Run	using historical data, past 100 years, plots
PHASE II: testing	
8. Sensitivity tests	initial values, attractiveness, coefficients, transportation
9. Policy tests	in all model sectors, emphasize transportation
10. Robustness tests	in normal business and population growth rate
11. Advisory Meeting #2	plan and hold meeting critique base run, sensitivity tests, define policy sets, review causal structure

PROJECT TASKS (con't)

Task	Description or Comments
	PHASE III: analysis
12. Policy Scenarios	based on meeting #2, show detailed output graphs
13. Documentation	flow chart, documented equations, technical description, output graphs, test tables
14. Advisory meeting #3	plan and hold meeting critique policy tests, scenarios, validation comments, audience and follow-on suggestions
15. Final report	results of validation, audience and follow-on suggestions reported to DOT, make final revisions in model and final runs and revise documentation appropriately as suggested in meeting #3.

TASK SEQUENCE

Task	1	2	3	4	5	6	7	8	Total
				Project Month After Initiation					
PHASE 1									
1. define zones	11								11
2. define clusters	10								10
3. equations	10								10
4a. prepare mtg #1	6								6
4b. hold mtg #1		11							11
5. debug METSIM		28							28
6. collect data	6	20	16						42
7. base run			6						6
PHASE 2									
8. sensitivity				6					6
9. policy tests				10	9				19
10. robust tests					4				4
11a. prepare mtg #2					11				11
11b. prepare mtg #2						11			11
PHASE 3									
12. scenarios						10			10
13. documentation							23	22	45
14a. prepare mtg #3							4		4
14b. hold mtg #3							9		9
15. report							5	21	26
Total Days	43	59	22	16	24	21	41	43	269

Pages 104 through 107 have been deleted.

APPENDIX C

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. Systems dynamics paradigm and generic non-linear dynamic feedback simulation were introduced as concepts for modeling relationships between urban transportation systems and other metropolitan area physical, demographic, economic, and fiscal systems.

Probabilistic Systems Dynamics Model

Report 450-107-04R

RESEARCH TO IMPROVE UNDERSTANDING OF TRANSPORTATION INTERACTIONS WITH SOCIETY

A STUDY DESIGN REPORT

Submitted to

U.S. Department of Transportation
Transportation Systems Center

under contract number

DTRS-57-80-C-00034

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March 10, 1980

CONTENTS

* Section not included

INTRODUCTION

Historically, 20 percent of the U.S. gross national product (GNP) has been devoted to transportation. That investment has resulted in very rapid increases in mechanization and mobility which, in turn, have produced the major changes in conduct of business and lifestyles witnessed during the 1950s and 1960s. The ascendency of private transportation has broadened the range of alternatives available to society and has led to evolutionary shifts in patterns of location, development, and travel. To the extent that we are financially and physically able, we individually strive for instant gratification of a seemingly insatiable, latent demand for freedom, comfort, and convenience.

But collectively, the interaction of transportation and society has led to dissatisfaction with the external costs; costs that come to dominate our thinking as our affluence grows. One now hears the call for a "socially responsible" automobile and observes international efforts to "reinvent the car." A day rarely passes that someone does not inveigh against urban sprawl, while industrial disperson continues. Our rail system is in a shambles at a time when energy prices are exploding. To compensate for energy costs, trucks get larger and cars become smaller to the detriment of safety. Inflation erodes newly won opportunities for leisure. Access requirements are changing radically as female participation in the labor force grows. Declining birthrates foretell an aging population. Single-person households and "serial polygamy" are growing social forces having ramifications for mobility. Ethnic and racial tensions may be leading to

a redefinition of the sense of community. It has been suggested that transportation has been used as much for escape as for access. More than 20 percent of United States households move each year. This migration has recently been at the expense of large cities and away from the industrialized regions of the Northeast and Midwest. The economy itself is in transition as we move from manufacturing to a service/information society.

Of course, it is increasingly recognized within all this turmoil that transportation is a societal subsystem, the optimization of which may be at the expense of competing and no less-essential sectors of society. For example, investment in revolutionary communication systems might be made to obviate the need for mobility by bringing ideas and things (e.g., catalog shopping with warehouse delivery on optimized schedules) to people rather than moving the people. The introduction of broad-based services via space satellite or fiber optical transmission could result in greatly increased sprawl exhibiting far fewer trips of much longer distance with significantly higher vehicle load factors. Energy would be conserved and (cold start) emission rates reduced.

Alternatively, changes in land use could enhance accessibility while reducing mobility. Society might choose to agglomerate rather than innovate for mobility, designing for a constructively heterogeneous environment of neighborhoods connected to centers of culture and industry by transmission lines and public transportation offering convenience, speed, comfort, enjoyment, and dignity.

Whatever answers may be forthcoming to the open and difficult question of desirable development patterns, a fundamental policy decision appears to be necessary at this juncture. That is, whether and how transportation should shape, rather than merely serve, the demand for mobility. In this

context, the role of transportation in society must be understood in terms of its ability to influence spatial, economic, and social structures as well as in terms of the impact of major changes in those structures on transportation. Hence, this study design addresses the long-term viability of our society with a concern not only for primary impacts but for the secondary (other physical) and tertiary (essentially social/institutional) phenomena as well.

Purpose of the Research

This program of basic research is intended to explore an innovative approach which will

- describe effects of major, long-term improvements in urban and intercity, public and private, passenger and freight transportation on the structures of United States society.
- evaluate the impact of no major improvement in the transportation infrastructure in terms of the value of mobility to society.
- compare relative advantages of cities and regions based on their unique transportation characteristics.
- find synergistic actions and policies beyond transportation development and investment that might be used to complement transportation improvements for marked benefits to society.

As interpreted by this study design, benefits to society are assumed to correlate with ecologically sound economic development which, in turn, leads to balanced growth of population based on area attractiveness.

Description of the Approach

Interactions of transportation, economics, energy, land use, housing, water, and sewer facilities as they relate to an expression of national urban and regional policy may be difficult to describe with anything but an intuitive modeling process. In recognition of the feedback loops

between transportation and society and the stochastic nature of exogenous factors that affect them both, probabilistic system dynamics (PSD) will be used as the innovative approach to gaining insight about transportation interactions. Not only does this approach recognize unprecedented events explicitly but, given their occurrence, it results in knowledge about both the model outcome and the changing structure of the model itself. Thus, the roles of transportation, society, and external factors (e.g., warfare in Middle Eastern oil-producing countries) can be understood in terms of their probabilistic and deductive relationships. The Futures Group is a pioneer in the development and use of PSD. We believe such an approach is dynamic, focused on long-term effects, amenable to modular construction so that large-scale model building may be avoided, adaptable to theoretical developments and empirical correlations, subject to validation by test against recent events, and potentially generalizable to accommodate all facets of transportation.

System dynamics was developed in the 1950s, based on concepts derived from servomechanism theory, to model and analyze systems that are usually depicted as a complex series of interlocking feedback loops. Feedback processes are a part of practically every decision system. As long as the system involves decisionmaking, is basically closed (i.e., has few important exogenous influences), and is continuous and deterministic, it is a candidate for system dynamics modeling. However, in many systems the decision environment is directly influenced by discrete events that may or may not occur and which may well be the most important influences on the system over time. Also, relationships among model variables and structure may change over long time spans because of causal forces within the system or because of the events occurring within or outside the system. In the case of transportation interactions with society, such changes should be

a part of the dynamics of the system and must be modeled with probabilistic system dynamics.

In the PSD approach, two processes are followed simultaneously: 1) the development of a system dynamics model to replicate the performance of the system being simulated and 2) the development of an event set which, when expressed probabilistically and linked to the model, will affect the system were the events to occur. In the PSD model the following new loops are utilized:

- Event-to-event impact. This cross-impact procedure deals with the effect of the occurrence of one event on the probabilities of the other events in the set.

- Event impacts on the model. This may take several forms. The actual structure of the model may change, coefficients of equations may vary, new terms may be added to or subtracted from the equations, etc. The process of associating events with model elements is facilitated by the fact that System Dynamics equations use coefficients that have physical meaning.

- Model impacts on the events. For example, as a particular model variable in an equation increases or decreases in value over the projected time interval, the probabilities of some or all of the events in the set may vary. The set will include technological, social, economic, and institutional events.

The system to be modeled will be regional with the scale of the region dependent upon problems of immediate interest and data availability. A large United States region has been selected for model development and will be discussed below. The major modules to be included in the model will cover transportation, of course, and communication as a technically interesting, if incomplete surrogate. In addition, business and environment modules will be included to represent the socioeconomic factors of the social system. Hence, the regional socioeconomic consequences of transportion investment may be analyzed within an atmosphere of technological competition.

Importance of the Study

Now that the United States has reached a level of affluence and maturity whereby social and environmental costs are weighed more heavily and pure mobility benefits more lightly, a new balance must be found for technological advances and massive investments in transportation. Futhermore, adjustments of energy prices to political intervention, such as the transition from past United States price controls to present OPEC taxes, may be distorting the cost of transportation improvements and operation to the point of violating the historic relation of transportation to gross national product. Thus, questions arise regarding transportation's claim to resources, and expenditures heretofore "allocated" to transportation may be "assigned" to other sectors of society, especially if transportation investment is perceived as detrimental to "desirable" development patterns and economic growth. This study is designed to illuminate the role that transportation plays in society and will be important to the degree that it reduces the uncertainty surrounding decisions, both large and small, regarding transportation's strategic place in the national fabric.

It is generally acknowledged that changes in transportation have accompanied changes in styles of living and doing business: the recent past has seen a vast increase in the range of alternatives available to society. However, the correlation of transportation investment with social progress is only poorly understood. Although one can but speculate on the study outcome, another example of its importance would be a demonstration that transportation investment relative to other social system infratructure is not all that important. Such a counterintuitive outcome could only be visible following calibration of the models estimating relationships and the conduct of sensitivity analysis.

The study and its design are also important because of the opportunity offered to distinguish between accessibility and mobility. Although the study does not become embroiled in location theory and land use beyond a macro-analysis, it does address one aspect of accessibility by explicitly examining the telecommunications/transportation tradeoff. The revolution in electronics and current conditions of energy price and availability beg for such analysis.

Perhaps the most important facet of this study is the inevitable connection between transportation and industry in terms of their contribution to environmental degradation. This connection is dramatized in the Clean Air Act Amendment of 1977. It has become increasingly clear, as state implementation plans are filed, revised and deferred, that industrial viability, not just economic development, may be jeopardized by the shear numbers and emission rates of vehicles in the transportation system. Of course, as adjustments are made to conserve energy and the environment, the value of time and regional productivity must be recognized explicitly.

Finally, this study is important because it grapples with the long-term spatial patterns resulting from the interaction of transportation with complex social and economic forces. Although the use of PSD demands a definition of a system and that system has been designated to be a region, the region need not be closed. And that is exactly in conformance with a major benefit of transportation investment: It allows a region that is deficient in resources (including talent) to import and also to export its products and waste. Although as presently structured, the model will not "know" the sources or sinks for flows across the boundaries, a measure of regional self-sufficiency will be available. Furthermore, as study success is demonstrated, the methods developed are easily transferred to other

regions for a more complete understanding of interregional competion, a subject of considerable interest to national policymakers.

Utility of the Results

The past 25 years have exhibited remarkable stability in spending patterns for transportation. For example, personal consumption expenditures for passenger transportation have held at 13 percent over that time and the user-operated portion of that has grown only slightly, from 92 to 94 percent. Now, however, with dissipation of the baby boom, environmental consciousness, energy cartels, life extension technologies, automation's contribution to leisure time, recognition of civil rights for the young/poor/elderly/handicapped, universal aspiration for personal growth and the magnification of the value-of-time by inflation, the role of transportation in United States society may be subjected to significant structural change. It is our belief that the modular approach to understanding that change described by this study design report, offers the potential for great insight for purposes of policy development and planning.

Although this approach is subject to the limitations in the data base, at the very least it can be used to define and justify regional data requirements and, further, the approach is resilient because of the ease with which it can accommodate judgment. Not only do the model equations use coefficients that have physical meaning, but PSD models exhibit the following significant advantages:

- The inclusion of events in the model allows occurrences outside the area of focus of the basic model to be taken into account in the model predictions. In this manner, any number of exogenous events may be included and the scope of the model is no longer limited strictly to the closed system defined by the system boundaries.

- The structure of the basic model itself becomes dynamic. Relationships among variables and even among sectors of the model may change with time as the impacts from other parts of the model and from the events accumulate.

- Policies can be tested in terms of their effects on the relationships among model variables, model structure or event probabilities. Policies that have their main impact on areas outside the basic model can still be tested for impact through the effect of those policies on exogenous events. Thus, a much more complete description of the side effects of policy decisions is possible.

Thus, study results will have high utility to policymakers and planners because the results can be presented in their (frequently qualitative and often judgmental) language. In addition, the study will be compatible with requirements for citizen participation in the planning process because, once the model assumptions are accepted, the model can be used as a tool for rapid experimentation. This is sure to be less costly and less risky than demonstrations with an actual system of the complexity described here. Hence, when a particular change suggested by a citizens panel produces a counter-intuitive result, that result can be isolated by tracing through the system and exact causes can be identified.

Also, as the model is currently structured, the scale of application is entirely dependent on the data base used. Although development will be based on a particularly interesting and large region of the United States, nothing precludes model application to smaller geographic areas such as states, air quality control regions or regional councils of local governments.

Finally, utility of results of the study will be enhanced by model implementation on a nationally available computer time-sharing service using a special computer language known for its ease of use. For example, the compiler, DYNAMO, has been developed over a number of years to service system dynamics models. DYNAMO accepts input in the form of normal

mathematical equations, provides extensive error diagnostics, and automatically formats the output. Thus, no extensive computer training is required by subsequent users of the model and the model is not a captive of the developing organization. Given that the model is useful to a number of levels of policy and planning, it will be easily transferred for extensive utlization.

STUDY DESIGN

This study is structured to explore the complex and often obscure role of transportation in society. One manifestation of that complexity is the transportation system itself. The system--actually, it is a societal sub-system--is comprised of many components and described by many attributes. Table 1 lists some attributes covering markets, modes, methods, service and purpose. Obviously more than one descriptor is necessary, even when merely conducting analysis of a single mode.

The other major aspect of complexity is the social system. The social system may be thought of as having both a physical and a metaphysical foundation. The physical base may be described as having a physical structure (people, buildings, means of production and transportation) and support for that structure in terms of factors of production (technology, energy and material). The metaphysical base would be the societal structure (values, customs, knowledge and institutions). Obviously, each important element of the social system is linked to the other.

Social systems are dynamic, exhibiting growth, stability and decline. The problem before us is to manage the transportation "portfolio" so as to stimulate growth or stave off decline. That problem is compounded by the potential for overdevelopment, the clear signs of which are energy and environmental problems and inordinant dependence on foreign resources. The United States, for example, is over 50 percent dependent on foreign

Table 1

ATTRIBUTES OF THE TRANSPORTATION (SUB)SYSTEM

Modes

- Bicycles
- Motorcycles
- Auto
- Taxi
- Bus
- Truck
- Rail
- Air
- Marine
- Pipeline
- Powerline
- Cable? Space?

Service

- Passenger
- Freight
- Energy
- Enlightenment? Entertainment?

Methods

- Manual/Automated
- Private/Public
- Guided/Unguided
- Canalized/Broadcast?

Market

- Urban
- Rural
- Intercity
- International

Purpose

- Work
- Shop
- Educate
- Recreate
- Socialize
- Perform Other Family Activities
- Gather Resources
- Dispense Products
- Dispel Waste
- Distribute Power
- Transmit Ideas?

supplies for more than a dozen commodities considered critical to the national economy.*

Overdevelopment has been attributed to the inclination of social systems to horizontally specialize functions and vertically centralize control. At the outset, the efficiency gains from specialization outweigh the added costs of centralized control. But eventually this pursuit of growth leads to consumption of abundance and a level of complexity which reverses the effect of past policies and practices and they become powerful forces for decline rather than for the stability that the socioeconomy seeks. Overdevelopment is an avoidable consequence if internal control is not ceded to external forces. This study design admits the potential for overdevelopment but focuses on the classical problem of (controlled) growth stimulation.

Despite this limitation, an enormous challenge is presented by requests for better understanding and analysis of transportation's role in the socioeconomic system. Very broad issues are involved because of the ubiquity of transportation. The study design which follows seeks to clarify those issues, for subsequent resolution by policy, using innovative, analytic techniques which accommodate the problem in terms of both a realistic and meaningful scope of the system and scale of application.

Attributes of the Social System

If the important elements of a social system are defined as the physical structure, factors of production and the societal structure, then their underlying elements may be further illuminated in terms of *their*

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*C. J. Ryan, "The Overdeveloped Society," *The Stanford Magazine* (Fall/Winter 1979).

attributes. An attempt has been made to do so here and to further refine the list by selection of a single descriptor most relevant to a series of closely related attributes. The descriptors, underlined to the left of the attribute lists on Table 2, offer a succinct list of potential concerns to the study design. Hopefully, this list both captures the essence of the social system and flags the truly important elements to be studied.

Major Elements for Study

It is immediately obvious that even the most abbreviated list of potential concerns transcends reasonable levels of effort for an exploratory phase of this research. Therefore, five major elements have been selected for study at a high level of aggregation: transportation, communication, economic development, the environment, and government. As demonstrated earlier, transportation, as one of these elements is quite complex. Most assuredly, the other elements rival transportation in complexity. So any representation of the major elements must be simplified to be tractible.

The basic approach taken, therefore, is to define each major element only so far as to demonstrate the parallel nature of transportation and communication, and then to link them to economic development by way of a common interest in environmental quality. Governmental presence will permeate the construct due to tax relationships with business and labor, and subsidy relationships with transportation, communication, and people in the system. What remains is to define enough variables to link these major elements at a high level of aggregation. Surprisingly, when this is accomplished, many of the social system descriptors discussed above are represented.

Table 2

ATTRIBUTES OF THE SOCIAL SYSTEM

Physical Structure

PEOPLE

Migration	Migration/Displacement
Mobility	Productions/Attractions/Mobility
Income	Income/Jobs/Unemployment/Age/Skills/Consumption/Recreation
Health	Safety/Security/Vandalism/Crime/Density/Number/Stress/Health

PLACES (Industrial, Commercial and Residential Buildings, Recreational Land, etc.)

Development	Development/Supply/Age/Value/Disruption
Accessibility	Accessibility/Location/Size
Land Use	Codes/Zoning/Open Space/Land Use/Site Availability/Density

MEANS OF COMMUNICATION

Availability	Availability/Complexity/Integrity/Security
Type	Information Type (Management/Production/Shipment/Consumption)
Quality	Bandwidth/Data Rates
Cost	Cost/Noise/Interference

MEANS OF TRANSPORTATION

Generalized Cost	Time for Access, Wait, Travel/Cost/Variability/Quality (Comfort, Compatibility, Privacy, Dignity, Loss & Damage, Cleanliness)
Flexibility	Availability/Complexity/Flexibility/Multimodality/ Competitiveness/Convenience
Congestion	Intensiveness/Circuitry/Congestion

MEANS OF PRODUCTION

Employment	Activity/Suppliers/Services/Employment Area
Inventory	Inventory Requirements/Quality Control
Market	Market Area/Shipment (Value, Density, Size, Perishability)

Table 2 (Cont.)

ATTRIBUTES OF THE SOCIAL SYSTEM

Factors of Production

FINANCE (Public and Private)

Investment	Capital/Subsidy/Risk/Investment/Inflation
Profits	Sales/Costs/Profits/Cash Flow
Taxes	Interest/Dividends/Taxes

MATERIALS (Natural and Artificial)

Support	Power/Water/Food/Weather
Depletion	Depletion/Renewal/Corrosion (Combustibility)/Recycling(Rehabilitation)

TECHNOLOGY

Innovation	Invention/Innovation
Productivity	Mechanization/Automation/Productivity

ENERGY (Primary and Secondary)

Fuel	Type/Fuel/Toxicity
Price	Consumption/Price/Supply

WASTE REPOSITORY (Drainage)

Pollution	Air/Water/Land/Noise/Vibration/Radiation

Table 2(Cont.)

ATTRIBUTES OF THE SOCIAL SYSTEM

Societal Structure

INSTITUTIONS

Governments	Labor (Unions)/Management/Governments/Consumer
Structure	Political Structure/Jurisdictional Conflict/Annexation/Redistricting
Community	Community/Ethnicity/Religions/Family
Complexity	Size/Complexity/Specialization/Complementarity/Stability/Barriers

CUSTOMS

Regulations	Tradition/Law/Regulation/Enforcement/Disobedience/Terrorism
Plans	Policy/Programs/Plans/Participation

KNOWLEDGE

Data Bases	Schools/Libraries/Contacts/Media/Data Bases
Education	Education/Propaganda/Rhetoric/Veracity

VALUES

Culture	Ethics/Morality/Prestige/Culture
Aesthetics	Lifestyle/Aesthetics/Wildlife, Scenic and Historical Sensibility

Causal Loop Diagrams for System Dynamics

In developing a probabilistic system dynamics model of any system, the first step is to organize the underlying structure of the system that is causing it to operate. This organization can be recorded in a causal loop diagram that shows all major cause-and-effect links and indicates whether the linkages between variables have a positive or negative reinforcing effect.

Figures 1 and 2 present two initial causal loop diagrams that relate important segments of society including the business/environmental, transportation and communication sectors. In the business/environment causal loop diagram, business investment increases employment and tax receipts. Employment in turn decreases unemployment, increases products produced, and increases congestion and pollution. Products produced decreases resources available but both resources available and products produced have positive influences on resources, product and people transported. Resources, product and people transported then feeds back positively to employment and business investment.

Congestion and pollution is increased by resources available and decreases labor supply and business investment. Labor supply acts positively on people informed which in turn increases employment. Labor supply increases resources, product and people transported, enhances tax receipts, and increases unemployment. Both unemployment and tax receipts increase public subsidy, which in turn increases employment and the labor supply. Finally, tax receipts have a negative effect on labor supply and business investment, while labor supply acts positively on business investment, thus completing the business/environment causal loop.

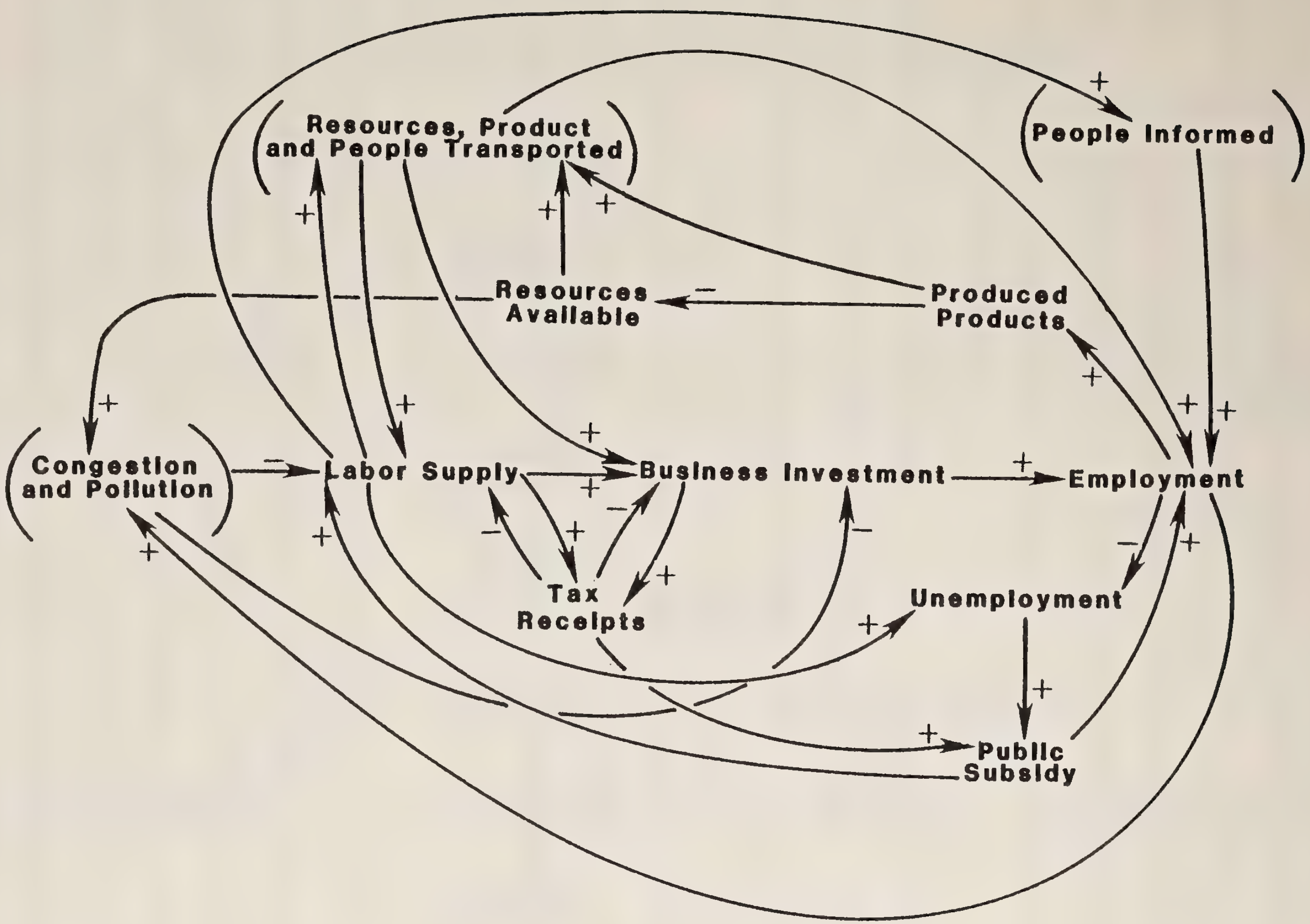

Figure 1. Business/Environment Causal Loop Diagram

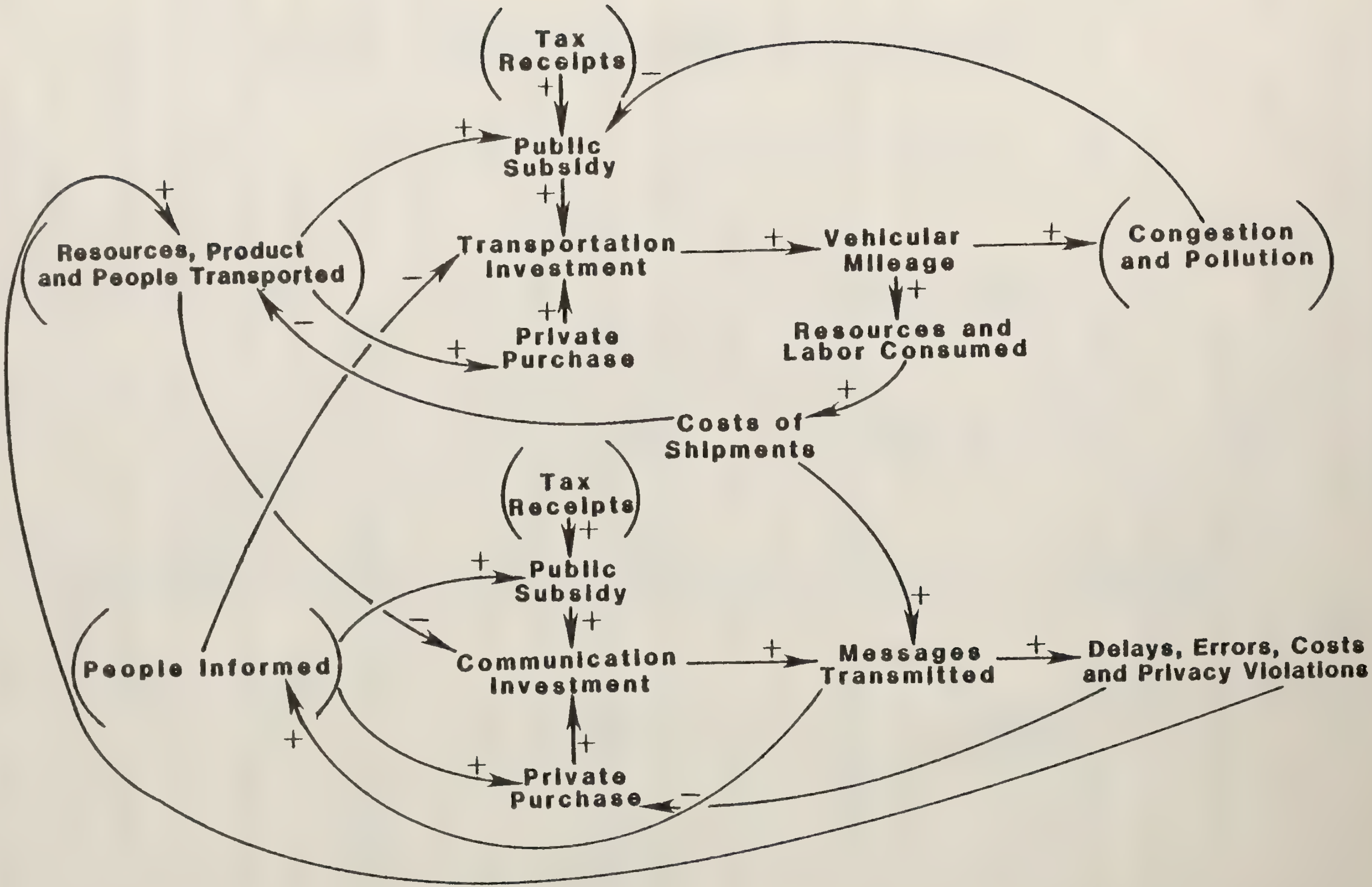

Figure 2. Transportation/Communication Causal Loop Diagram

In the transportation/communication causal loop diagram, transportation investment increases vehicular mileage which in turn increases resources and labor consumed and congestion and pollution. Congestion and pollution feeds back negatively to public subsidy (tax receipts act positively on public subsidy) which then increases transportation investment. Resources and labor consumed increase the costs of shipments which in turn decreases resources, product and people transported leading to increased public subsidy.

Communication investment is decreased by resources, product, and people transported but is increased by public subsidy via tax receipts. Messages transmitted are enhanced by costs of shipments and communication investment. Messages transmitted increase people informed which in time decreases the need for transportation investment. Messages transmitted also increase delays, errors, costs and privacy violations which leads to an increase in resources, product, and people transported and a decrease in private purchases of communication equipment. People informed act positively on public subsidy and private purchases which both enhance communication investment, completing the causal loop.

These two major causal loops are linked together with the variables resources, product, and people transported, tax receipts, congestion and pollution, and people informed. Examining the two major loops in the transportation/communication diagram, i.e., the one involving transportation investment, vehicular mileage, congestion and pollution, and public subsidy; and the one involving communication investment, messages transmitted, delays, etc., and private purchases, it is noted that both are complex, negative feedback loops suggesting potential for instability. However, their ultimate behavior is likely to be either gradual adjustment or damped oscillation rather than continued or explosive oscillatory response.

Analyses relating to the trade-off between communication investment and transportation investment will be discussed in a subsequent section.

Scale of Application

This study design report outlines an approach to specific analyses of the consequences of investment or policy changes in transportation systems in the New England Region. The New England Region was chosen for the following reasons:

- The home office of The Futures Group is located in the region and many of the employees have lived in the region for years and are aware of the transportation-related problems.

- The region has several important problems that affect transportation in the region, e.g., the difficulties associated with the northeast rail system and the cost and supply of energy.

As will be shown in the following sections, a probabilistic system dynamics model will be developed from the causal loop diagrams shown in the previous section that can accept a variety of transportation investment actions or policy changes, and generate impacts on important variables in the region such as business investment and pollution. Through these analyses, The Futures Group intends to demonstrate the usefulness of this modeling technique in examining desired transportation-related impacts.

Probabilistic System Dynamics and Some Key Events

Simulation models may be constructed for a variety of purposes. Among these purposes are

- testing a theory of system behavior.
- projecting the general behavior of a system.
- forecasting specific system parameters.
- designing policies to affect system behavior.

Except for the use of a model to test a theory of specific behavior, the uses of simulation models all have one characteristic in common--they deal with the future behavior of the system. Whether the goal of a modeling effort is to project the general behavior pattern of a system or to forecast specific values of system parameters, the models are used to develop information about the future. Most models, however, are based on the past. Information about past relationships is used to define the relationships in the model, which are then used to simulate the future. Any model that is based entirely on the past will be useful only for exploring the very near-term future. The exact time period for which it may be useful depends on the type of system being studied. Some systems have high inertia; that is, they change only very slowly or only in response to very large impacts. The population of a country is an example of a system with relatively high inertia. A projection of future population based only on the past would probably be fairly accurate for ten to twenty years into the future. Only very large impacts, such as war or disease epidemics, are likely to cause population growth to depart significantly from past trends over this time period. On the other hand, the price of beef is an example of a low-inertia variable. The price may change drastically from year to year in response to small changes in weather, corn prices, consumer preference, etc. Any forecast of beef prices based only on past data is not likely to be accurate for even one year's time. However, even the population projection will ultimately be wrong because the future will not be simply a reflection of the past. Changes are occurring every day that ensure that the future will be different from the past.

Some modeling techniques may be based entirely on past data such as curve extrapolation. Often, however, in applying these techniques it is

recognized that simple extrapolations of past data do not produce reasonable forecasts; thus the analyst's perception of the future is introduced into the projection process by setting boundary conditions on extrapolations, judgmentally adjusting the output of mathematical models, etc. Other modeling techniques include some information about the future within the model itself. System dynamics models generally contain a relatively high degree of information about the future. This information may be in several forms. Nonlinear relationships included in system dynamics models through table functions often depend on historical data for part of the range and on the modeler's perception of the future shape of the relationship for another part of the range. Relationships among variables that are not apparent today may be included in the model structure because of the assumed importance of these relationships in the future. However, an important class of information about the future--future events--is not usually considered.

Future events are discrete, specific occurrences that have not necessarily occurred in the past but might occur in the future. Because these events have not occurred in the past, they will not be included in models based largely on the past.

<u>The need to consider future events</u>. Why is it important to consider the influences of future events, especially when those events are not certain to occur at any time in the future? In order to answer this question, it is useful to restate the purposes of most modeling efforts: to project general system behavior and to forecast system variables. In order to project the behavior of a system, it is necessary to consider all the influences acting within the system. In many cases the only important forces within the system are continuous forces that can be modeled without considering

discrete events. However, in many other cases a system responds not only to continuous forces but also to discrete events. In these cases the system behavior cannot be adequately captured unless events are considered.

An example of a system that is susceptible to discrete events is, of course, the transportation system in the United States. Until 1973, this system was reasonably well behaved and could have been simulated well with a continuous simulation model. In 1973, however, an event, the Arab oil embargo, caused a profound shock to the system. The subsequent dramatic rise in the price of gasoline has recently culminated in large demands for small, high-mileage cars that cannot be entirely satisfied by domestic and foreign manufacturers, and little demand for larger cars leading to demands for restrictions on foreign imports by domestic manufacturers and the United Auto Workers. This event has also induced impacts in other parts of the transportation system as well as throughout the economy.

The transportation system is not likely to remain free from the impacts of events in the future either. Among the events that could significantly affect the behavior of the system in the future are

- gasoline rationing imposed.
- Mexico guarantees oil to United States.
- real price of oil drops dramatically.
- ICC role greatly diminished: transportation deregulated.
- widespread use of electric cars.
- warfare in Middle Eastern oil-producing countries.
- workable audio-video communication centers installed in all major cities.
- legislation imposing a moratorium on new nuclear plants.

- heavy migration to the South and West producing dislocations due to sudden growth.
- recombinant DNA advances have major impacts on energy supply and demand.
- development of an inorganic synthetic polymer that creates a polarized hydrogen bond to separate oil and water, greatly enhancing secondary oil recovery and oil-spill cleanup.

It is clear that most, if not all, of these events would have major impacts on our society, particularly in the transportation sector. For example, if electric cars gain widespared favor, this will have obvious major implications for the automobile manufacturers and their suppliers, the gasoline refiners, owners and suppliers of service stations, electric utilities and battery makers. Such an event does not yet have a sufficiently high probability to include it with certainty in a regular system dynamics model; its omission from such a model could, however, lead to highly misleading results. Probabilistic system dynamics allows such events to be included in accordance with their estimated probabilities thus creating a more realistic model of future developments.

Therefore, whether a model is being used to explore the general behavior of the system or to forecast system parameters, it must include a consideration of these discrete events. In many cases the influences of events occurring either within or outside the system may become the most important influences on the system over time.

Many system dynamics modeling projects do, in fact, consider unprecedented events, but the events are not a part of the model itself. They are usually considered one at a time in a series of sensitivity runs. In this approach the analyst considers an individual event, asks himself what the effect on the model would be if the event did occur, makes the appropriate

changes in the model, and produces a new run. Additional events may then be considered in the same manner. Thus, the process is essentially one of considering each event in isolation from all of the other events or policy runs that may be made. Unfortunately, this approach to assessing the influences of events is not always adequate.

When the influences of events are studied in isolation, three types of interactions are overlooked. First, the influences of model parameters on event probabilities are not considered. If an event is tested by simply assuming that it occurs in one particular run of the model, there is no opportunity to see how changes in model parameters might affect the likelihood of that event. The second type of interaction that may be missed unless events are made a part of the model is event-to-event interactions. Many events are closely related to each other. The occurrence of one event often makes other events either more or less likely to occur. Finally, unless events are included in the model, the combined effects of several events occurring in sequence may be missed. Of course, if only two or three events are being considered, all the combinations of occurrences and nonoccurrences and the timing of event occurrences might be tested through separate runs; but as the number of events increases beyond a very small number, this approach clearly becomes impossible.

<u>The need to consider uncertainty in exogenous inputs</u>. All models contain some exogenous inputs. These inputs may take the form of historical data, future projections, judgment, or system parameters. In most cases these inputs are uncertain to some degree. However, in many models, once the specific values for these inputs are decided upon, the uncertainties are forgotten and the models are run as if these inputs were exact. The output

of the model, therefore, often conveys a degree of accuracy that is not real. Even if the user realizes that the accuracy of the model is limited by the uncertainties in the inputs, he may not have a good idea of how those uncertainties translate into uncertainty in model output. Often, an attempt is made to gain this understanding by performing a series of sensitivity runs, varying the inputs one at a time. This is only of limited use since all the combinations of variations in input values probably cannot be tested. Thus the user is left with, at best, a limited understanding of the uncertainties involved in model output.

A better understanding of the uncertainty is desirable for two reasons. First, only by understanding the range of output that is likely can the user evaluate the risks involved in certain actions. If, for example, a model shows that future demand for airline travel is likely to be at a specific level, airport capacity may be increased to meet that demand. However, because that demand projection is uncertain, there are risks involved in planning to meet that demand. If demand actually turns out to be less than projected, an overcapacity situation, with excess costs for construction, could result. On the other hand, if demand turns out to be much more than expected, an undercapacity situation with the possibility of congestion and increased accidents could result. The planner cannot adequately evaluate these risks if he does not know the uncertainty associated with the model output.

The second reason for desiring uncertainty ranges for output variables is that some actions may have as their principal effect the reduction of uncertainty. In a highly uncertain planning environment, any action that can reduce uncertainty is worthy of consideration. Without a measure of

uncertainty to begin with, however, such considerations would not be possible.

For simple models it is often possible to calculate the uncertainty in the output directly. However, for large simulation models this approach is not possible. Therefore one must adopt a Monte Carlo approach in which a number of separate runs of the model are performed. For each run the values of the input variables are determined by random selection from their range of uncertainty. The spread of output values for each model variable across all Monte Carlo runs determines the effect of uncertainty in those variables. Although this approach increases the computer time and costs relative to regular systems dynamics models, the quality and usefulness of the output amply justify the additional cost.

Event selection. The first step in adding uncertainty to a simulation model is the selection of the events to be used. The events selected for use should be concisely written statements about future changes whose occurrence would have significant impact on the model output. The analyst can go through the list of model variables and ask himself, for each variable, "What future changes might affect this variable?" A literature search is often the most fruitful method for generating an event set. Other techniques include brainstorming, Delphi questionnaires or interviews.

The number of events that will be in the final event set depends on the model being used. However, since each event requires additional work and expands the size of the model, it is important to limit the events to only those that have significant impact. It has been the experience of The Futures Group that an event set containing 15-20 events is usually sufficient.

Event-event interactions--cross-impact analysis. When future events are added to a simulation model, there are two kinds of interactions that

must be considered: event-event interactions and event-model interactions. The approach to event-event interactions used here is based on cross-impact analysis; it is one of the most widely used techniques for studying the interactions of events.

The cross-impact analysis method is an approach by which the probabilities of an item in a forecasted set can be adjusted in view of judgments concerning potential interactions of the forecasted items. Most events and developments are in some way related with other events and developments. A single event, such as the production of power from the first atomic reactor, was made possible by a complex history of antecedent scientific, technological, political, and economic "happenings." In its turn, the production of energy from the first atomic reactor influenced many events and developments following it. In a sense, history is a focusing of many diverse and unrelated occurrences which permit or cause singular events and developments. From these flow an ever-widening tree of downstream effects which interact with other events and developments. It is hard to imagine an event without a predecessor which made it more or less likely or which influenced its form--or to imagine an event which, after occurring, left no mark. This interrelationship between events and developments is called "cross impact."

Once the event set is determined the next step is to estimate the initial probability of each event. In most cases the approach to estimating initial probabilities assumes that the expert making the probability judgments has in mind a view of the future which serves as a background for his judgments. Thus in estimating the probability of each event, the probabilities of the other events are taken into account. For example, a person may think that the likelihood of gasoline rationing being imposed is very high partially

because he also believes that oil will continue to be in short supply. In effect the events are being cross-impacted in his mind. To ask that the effects of other events be disregarded would invalidate much of his expertise. In this approach the initial probabilities and impact judgments reflect the expert's view of the expected future situation. The cross-impact technique is used to show how changes in that situation (the introduction of new policies or actions, the unexpected occurrence of an event, changes in system behavior, etc.) would affect the entire set of events.

The next step in the analysis is to estimate the conditional probability matrix. Impacts are estimated in response to the question, "If event m occurs, what is the new (conditional) probability of event n ?" Figure 3 provides an example of such an exercise. The first column of numbers suggests initial probabilities for the three events shown. The next three columns show a possible set of conditional probabilities. For example, if event 1, gasoline rationing imposed, actually occurs, this would have no effect on the probability of event 2, Mexico guarantees oil to the United States (unless this was a part of such an agreement), but may have some effect on event 3, widespread use of electric cars, by creating more demand for such cars. Therefore the probability of event 3 was raised to 0.10 from 0.05. Similarly if event 2 occurs, then gasoline rationing has less urgency and its probability is revised to 0.10. This more reliable source of oil may also decrease slightly the incentive to produce electric cars. If event 3 occurs, gasoline rationing would presumably not be needed, dropping its probability to 0.05, but this should have no effect on event 2. In a probabilistic system dynamics model run, when specific events occur, the probabilities of the remaining events are revised in this way. These

IF THIS EVENT OCCURS	INITIAL PROBABILITY BY 1985	THE PROBABILITY OF THIS EVENT BECOMES:		
		1	2	3
1. Gasoline rationing imposed.	.25		.40	.10
2. Mexico guarantees oil to United States.	.40	.10		.03
3. Widespread use of electric cars.	.05	.05	.40	

Figure 3. Sample Cross-Impact Matrix
Showing Conditional Probabilities

conditional probabilities must satisfy rules of probability and therefore must lie within numerical ranges based on the magnitude of the initial probabilities of all events. The program used to execute the cross-impact analysis automatically checks to see that the conditional probabilities are within the proper limits.

Event-model interaction. The determination of when or if an event occurs within the system dynamics model and therefore when its impact on the model should be felt, can be handled by using random numbers. For each solution interval a random number between 0 and 1.0 is generated and compared with the probability of an event happening during that solution interval. If the random number is less than or equal to the probability of the event, the event "occurs" and its impacts are calculated. Otherwise, the event does not occur during that solution interval.

Of course, it is not necessary to actually consider events as occurring or not occurring. Expected value impacts of events may be calculated. That is, the impact of an event on the model and on other events could be calculated at all times, but would be discounted by the probability of the event. Thus if an event concerning a 20 percent increase in the price of coal had a 50 percent chance of happening, the expected value of the impact would be .50 x 20 percent, or a 10 percent increase in the price of coal. This procedure may be useful for some events where the event is really the expression of a trend, such as increasing coal prices. However, it is not desirable for most events that are discrete changes. It would not be reasonable, for example, to say that because a nuclear moratorium had a 50 percent chance of occurring, the construction rate of new nuclear plants

would be reduced by half. Expected value calculations in such instances can give rise to unrealistic results and should therefore be avoided.

These events may be incorporated within the model in a variety of ways; however, most of the impacts may be expressed in one of two ways. One method is simply the addition of a multiplier to the equation for a particular variable. If the impact of an event is to increase the price of a commodity by 10 percent, for example, the calculated price may be multiplied by 1.10 if the event occurs, and by 1.0 if it does not.

The second approach is to write separate equations describing relationships with and without the occurrence of the event. For example, a separate set of equations could be written describing the choice of a generating plant in an electric utility model, with and without a nuclear moratorium. In one case nuclear energy would be included as one of the options that might be chosen; in the other case it would not be available. Suitable multipliers related to the occurrence or nonoccurrence of the appropriate events can then be used to turn on and off the appropriate set of equations.

From the other perspective, the impacts of model variables on event probabilities can be handled in the following manner. A series of judgments is made expressing the probability of an event as a function of different levels of a model variable. These probabilities can then be related to the initial probability of the event. For example, assume the likelihood of a nuclear moratorium occurring by 1990 is related to the amount of installed nuclear generating capacity. It might be estimated that the probability of the nuclear moratorium taking place would be .05 if nuclear capacity represented only 10 percent of all capacity, .15 if nuclear reached 25 percent,

and .30 if nuclear reached 40 percent of total capacity. The strength of the impact could then be expressed as a table function of the percentage of total capacity that is nuclear. Figure 4 provides a pictorial view of the ideas expressed in the previous paragraphs.

Once the estimates of initial probability and impacts have been made, the model simulation can proceed as follows:

1. The impacts of model variables on event probabilities are calculated according to the specified impact relationships.

2. Each event in the model is tested for occurrence.

3. For each event that occurs, impacts on other event probabilities are calculated.

4. The impacts of each of the occurring events on model variables are calculated.

5. The rest of the interactions of the model variables are calculated.

6. Steps 1 through 5 are repeated for each solution interval of the model.

Scenario generation. Each separate run in a Monte Carlo set is, in fact, a future scenario. Specific values for exogenous inputs are selected at the beginning of the run, and a pattern of event occurrences is generated during the run in response to event-model interactions. Thus, the model can be used in this mode to generate future scenarios. In most cases, use of the model for scenario generation would have the model respond to certain specified conditions. For example, the analyst might specify that two or three events should occur in certain years, and that the value of a particular input variable should be set in the upper part of its range. These conditions can be imposed on the model and the run performed. The result will be values for output variables and a pattern of event occurrences and

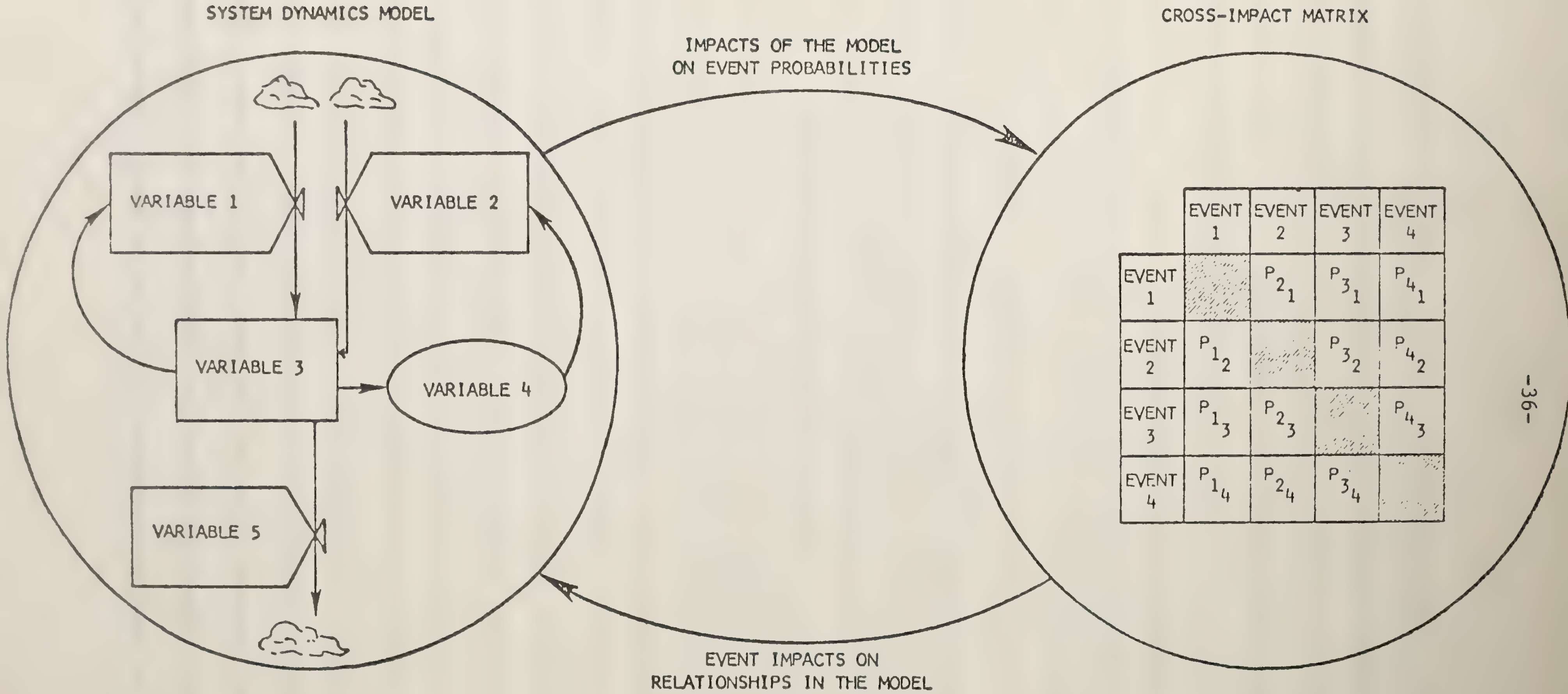

Figure 4. Impact Loops in Probabilistic System Dynamics

nonoccurrences that represent a consistent scenario. In effect, the model has been used to show likely consequences of the specified conditions by developing a complete scenario that is consistent as well. It is, of course, not the only possible outcome given those conditions; but it does represent a consistent scenario derived from those conditions.

Model validation. There are basically three ways that the validity of a simulation model can be assessed. They are

- comparing the output of the model over some historical time period with actual history.
- comparing the projections of the model with actual system behavior as time passes.
- judging the reasonableness of the behavior of the model under a variety of imposed future conditions.

Comparing the output of the model over a historical period with actual history does not provide validation of the probabilistic portion of the model since the past conditions are already determined. It is impossible, for example, to test the cross-impact matrix by comparing its output with historical data simply because all the events are future events. It is possible to add past events to the model to show how they have influenced past behavior, and, in fact, this has been done, as have historical validations of the cross-impact technique. This does not, however, validate judgments about future event probabilities and relationships.

Comparing the output of the model with actual developments as time passes can be a useful, if somewhat lengthy, validation procedure. There are two important considerations to keep in mind, however. First, because the model produces ranges for output variables, the comparison of model projections with actual fact may only involve deciding in what part of the range the actual value appeared. If the actual value appears at the very

edge of the range it could still be true that the model correctly calculated the uncertainty distribution for that variable, but that a relatively unlikely future developed. Of course, if it is possible to rerun the model under exactly those conditions that did develop in a scenario fashion, then it would be useful to compare model output with fact.

In many cases, however, the comparison of model performance with actual system behavior as time unfolds is more a validation of the model builder's perception than of the technique used. The kind of probabilistic model to be developed here includes much judgment. If the judgment of the model builder was good, a complete set of events developed, and probabilities and impacts well judged, then the model may perform well. In either case the performance of the model over one period of time does not necessarily mean that the model will perform well over a different time period, just as the correct forecast of an election by a political expert does not mean he will forecast the next election correctly. Of course, if a modeling team builds an impressive track record over time it creates some confidence in their expertise, but it does not validate their next modeling effort.

It is comparing the behavior of the model under a variety of imposed future conditions that the validity of probabilistic models is best assessed. A variety of plausible future conditions is developed and imposed on the model. The behavior of the model is then examined to see that it behaves, in the opinion of experts, the way the true system could reasonably be expected to behave. This may well be a dynamic assessment. If model behavior under a particular set of conditions at first seems to be counterintuitive, the users should examine the model interactions in detail to determine what produced that behavior. They may decide that those interactions are valid, in which case they have learned something about the

system; or they may decide that they are not valid, in which case the model must be changed. It is through this process that probabilistic models are best validated and improved, and this will be the validation process utilized predominantly in the study.

Opportunities for Analysis

The causal loop diagrams presented in an earlier section suggest several interesting areas for analysis and, in fact, the loop structure was intentionally assembled as shown in order to address specific questions. Two areas of prime importance will be discussed in this section:

- The ability of communication systems to reduce the need for transportation infrastructure.

- The role of transportation systems in the trade-off with business development under federal air quality standards.

The rapid proliferation of communication devices and computer terminals and the growing potential for further explosive growth in these areas in the next two decades opens promising opportunities for valid trade-offs between investments in transportation systems and investments in communication systems. As our nation continues its transition to an information society, increasing number of workers will be engaged in the creation, collection, organization, storage, manipulation and dissemination of all types of information. With the widespread availability of communication devices and computer terminals, one may engage in such activities at almost any location. This clearly opens the possibility of significantly reduced use of transportation systems in relation to an individual's work duties. For example, one interesting idea is that of "distributed companies," where employees of one enterprise spend significant amounts of time at work locations near their home (or in their home) using communication

devices to interface with other employees, and only occasionally visit "home base." The work locations house other employees who live nearby and work for a variety of companies. Such a scheme appears workable for a predominantly information-processing company and offers significant reductions in travel time for its employees.

Another idea, whose substance is contained in one of the future events listed in the previous section, is the establishment of high-quality audio-video communication centers in all major cities. The availability of such centers, open to all who wish to use them on a scheduled basis, clearly has the potential for reducing intercity travel. These and other trade-offs between transportation and communication will be investigated via the transportation/communication causal loop diagram.

Data sources linking these two areas are limited or nonexistent since the impacts will arise with new uses of existing and new technology. Therefore, several kinds of assumptions concerning these links will be introduced using table functions. Then through the various feedback loops, one can examine the impact of specified transportation investments on communication investment and usage and vice versa.

Questions relating to the issues surrounding transportation, business development, and air quality can be investigated within the business/environment causal loop diagram. Particularly in the New England Region, there will be major difficulties during the period 1983-1987 in attempting to meet the federal air quality standards. If these standards are not met, federal money may be denied to the region and many types of business development severely restricted. To the extent that the private automobile contributes to pollution in the region, this portion of the socioeconomic

system will receive commensurate attention. Therefore, it is clear that in the next decade and beyond, investments and policy changes directed at the transportation system in New England have the potential for major impact on the economic health of the region. This, in turn, has implications for the attractiveness of the region in terms of the desire of individuals and corporations to locate in the area. The question of relative attractiveness of the various regions is discussed in the section on potential extensions.

Returning to the main issue, several types of transportation investments will be investigated during the study and their impacts assessed. For example, an auto inspection plan for the region can be introduced and its impact on pollution levels and economic health of the region will be derived. Similarly, other investment/policy actions will be introduced into the PSD model, subjected to the event list, and their impacts on the region noted.

To illustrate the method of probabilistic system dynamics, consider the vehicular mileage/congestion and pollution link in the causal loop diagram in Figure 2, and the conditional probability matrix in Figure 3. If event 3, widespread use of electric cars occurs, then levels of nitrous oxide will be reduced. Consider the rate and level equations:

RNO.KL = (VM.K-E3*EVM.K)*NOVM.K+HIO.K (1)

NO.K = NO.J+DT*(NNO.JK-ANO.JK) (2)

where

RNO.KL = Rate of nitrous oxide creation between times K and L

VM.K = Vehicle miles during time K

E3 = Indicator variable

EVM.K = Electric vehicle miles during time K

NOVM.K = Nitrous oxide emissions per vehicle during time K

HIO.K = Heavy industry output of nitrous oxide during time K

NO.K = Level of nitrous oxide during time K

NO.J = Level of nitrous oxide during time J

DT = Solution interval.

NNO.JK = New nitrous oxide created between times J and K

ANO.JK = Nitrous oxide absorbed between times J and K

The indicator variable E3 takes on the value 1 if event 3 occurs, and 0 if the event does not occur. If E3 is 0, this reduces the rate of nitrous oxide build-up occurring in equation (1), and this carries through to the level equation (2). This simple example shows one method by which the probabilistic system dynamics technique is implemented.

Supporting Data and Related Work

A great number of sources of regional data have been identified which will support the current effort. Government and private sources have been identified and are listed in Appendix B. Of particular relevance are secondary data sources compiled by the Federal Reserve Bank of Boston and the New England Regional Commission.

The Federal Reserve Bank of Boston sources include the monthly "New England Economic Indicators" which include data by state and by major area on production, employment, construction, consumer, financial, and energy indicators, as well as the annual "Gross State Product" including data by state derived from the U.S. Department of Commerce personal income data.

The New England Regional Commission (NERComm) maintains two data bases of particular relevance. The first is the New England Multimodal Transportation Research Information Center (NEMTRIC) and includes more commonly available regional data from both federal and nonfederal agencies, including the Federal Highway Administration, the Federal Aviation Administration, and other modal agencies of the Department of Transportation; the Interstate Commerce Commission; national economic data sources, etc. Investment information is available by carrier and by state, and in particular detail for investments along the Northeast Corridor. The New England Energy Managment Information System (NEEMIS), also maintained by NERComm, contains energy consumption data by state and by product (current through 1977) in sufficient detail to provide a useful measure of transportation consumption as well as consumption in other major sectors.

As segments of the PSD model progress through levels of disaggregation, model data requirements will indicate the adequacy of the data used earlier. Needs for additional data will be identified and data files will be augmented as necessary from sources identified in Appendix B as well as other sources encountered in the course of the study. Where information needs are identified to which the model is particularly sensitive and for which no sources can be found, the study team will flag opportunities for future data collection but develop appropriate methods for introduction of judgmental data into the model.

Searches were conducted of the National Technical Information Service, Smithsonian Science Information Exchange, and Enviroline data bases to identify related modeling efforts. The following studies and articles appear relevant:

- Dyers, C. E., G. R. Cicky, and M. M. Stein, Maryland Department of Transportation, "Measuring Urban Transportation Investment Needs," Traffic Quarterly, Vol. 33, No. 3, pp. 363f., July 1979.

  A method of estimating investments required for urban transit system development is presented. The methodology used in formulating the investment model is described. State transportation data were tabulated and computer-coded. Socioeconomic variables employed in the investment model are described. The program provides information on the nature and magnitude of public transportation needs in the United States, and yields a set of structural equations that can be used to determine transportation needs.

- Barber, G. M. (Northwestern U.), "Regional Transport Investment Planning," American Geographers Association Annals, Vol. 68, No.3 p. 384, September 1978.

  Strategies that can be implemented in regional transport investment planning are discussed. Suggested are ways to ensure proper investment decisionmaking when planning variables are uncertain. Models that can be used to determine minimum levels of capital investment, transport project robustness, and project stability are presented. The models are used to evaluate the transport investment alternatives for a development project.

- Putnam, S. H., The Interrelationships of Transportation Development and Land Development (Washington DC: DOT-FITWA, September 1976).

  No system dynamics models were identified that specifically relate the transportation, communication, environmental, social, demographic, and economic parameters addressed in the current study. However, an ever-increasing body of literature exists which addresses separate components of these interrelationships. While an exhaustive list of these studies would require a separate volume, a selected sample from our library is presented in the "Related Studies" section of Appendix B.

- Putnam, S. H., The Interrelationships of Transportation Development and Land Development (Washington DC: DOT-FITWA, September 1976).

  Reports on computer simulation which integrates land-use models with transportation network models, permitting analysis of interrelationships between land-use patterns and transportation flows.

Potential Extensions

A regional model, such as the one being discussed in this study design, provides an excellent jumping-off point for developing macro or micro models that relate transportation systems to important areas of society. Figure 5 provides a block diagram view of the possible avenues that may be pursued.

The ultimate development of a model linking all regions in the United States should proceed in two phases. After a useful PSD model of the New England region has been developed and validated, similar models for remaining regions in the United States can be constructed. The selection of regional boundaries will be made by considering such factors as homogeneity, existing transportation infrastructure, and data availability. The second phase then relates the regions with respect to flows of people, resources, products, pollution, and capital, all as a function of changes in transportation systems.

The regional models will describe impacts within the region on those variables displayed in the causal loop diagrams. This analysis will be done with adequate but minimum assumptions about flows into and out of the region. In the second phase of the interregional model development the emphasis will be on describing flows between regions and assessing what portions of these flows can be attributed to changes in transportation systems. For example, a typical question of interest will be, To what extent does the existence or quality of particular intra- or interregional transportation systems influence an individual's or corporate decision to move from one region to another? Similar questions pertaining to resources, products, pollution and capital will also be of interest. The interregional model will be more macro in character than the regional model, and will be structured to allow questions suggested above to be answered. An appropriate initial size and level of

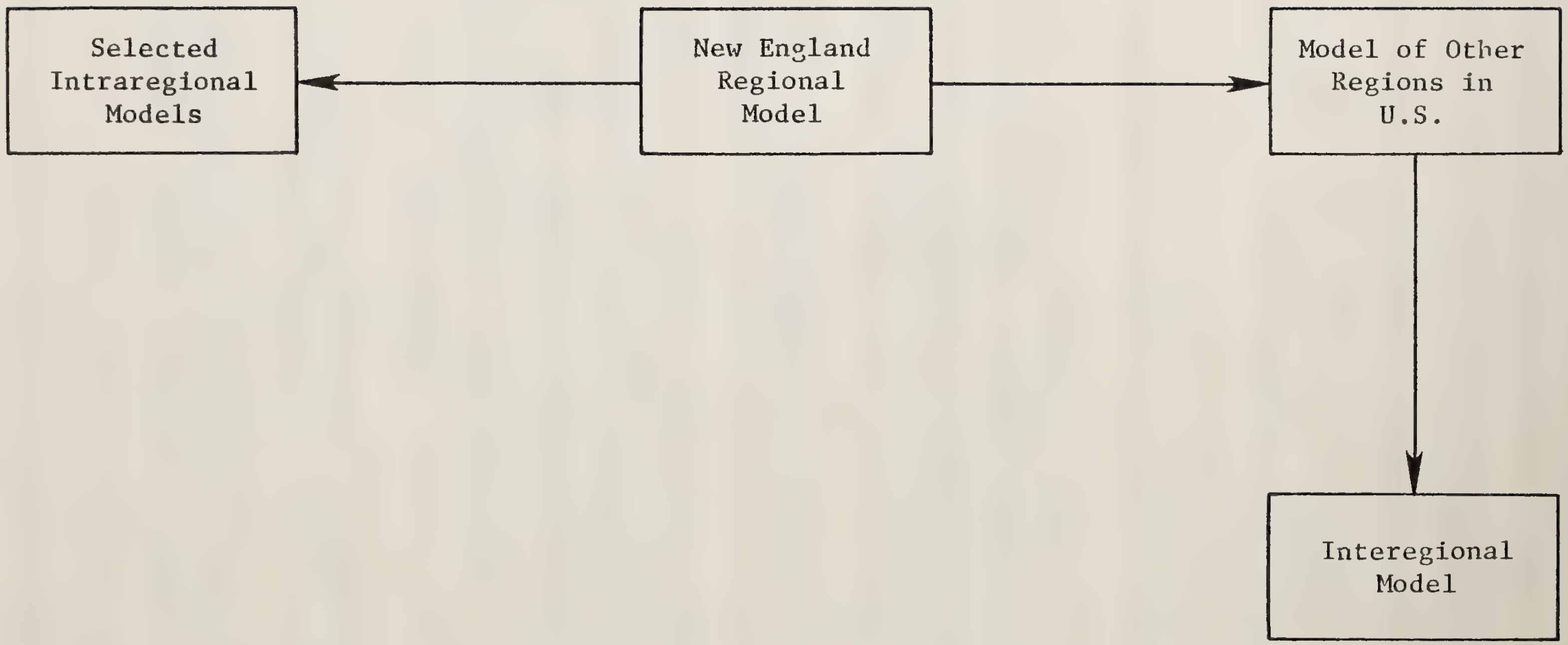

Figure 5. Potential Extensions from New England Regional Model

aggregation for the model should be similar to Forrester's World Dynamics Model. This will answer the question as to whether such a model can be useful, and if so, provide important results. A somewhat larger, more detailed model can then be developed as necessary. The event list for such a model will be similar to the list used in the regional model but since the structure and level of aggregation in the model will be different, the event-model interactions will take on a different character.

Clearly, such a model can be used to examine a question of major importance to transportation planners, i.e., How does transportation influence the comparative advantage of regions with respect to other regions? The Futures Group believes that the controversy over federal involvement in regional development is of such importance that the development of a model that is focused on this question alone can be fully justified.

An obvious additional avenue for development is the construction of selected intraregional models. Here one can consider modeling metropolitan regions as was done in Forrester's Urban Dynamics, specific systems within cities, or larger areas such as those associated with air quality control regions or regional planning commissions. Such models, depending on their purpose will generally include less aggregated variables than those contained in the regional models. A major difficulty here is the availability of data sources to support the relationships between variables. Information on flows of people and products into and out of arbitrarily selected areas may be nonexistent and data relating to the economic and transportation processes may have to be extrapolated from data sources pertaining to larger areas with the use of simplifying assumptions. Nevertheless, after the regional and interregional models have demonstrated their usefulness, several appropriate smaller areas should be subjected to the PSD modeling process.

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MASTER PROGRAM SCHEDULE

This study design lends itself to a well-defined series of tasks. The modeling techniques are well established. The multidisciplinary organization interested in performing this work has many years experience in understanding complex relationships of technology to society. And finally, the secondary data necessary to support this study appear to be available. Where that assertion proves to be optimistic, some primary data can be gathered or judgment used because the region selected for anaylysis includes both the sponsoring agency and its contractor. Therefore, the period of performance for this innovative yet highly aggregated probabilistic system dynamics modeling of the role of transportation in society should not exceed one year.

Tasks To Be Performed

In order to accomplish this research eight tasks are involved. They are illustrated in Figure 6. These tasks are predominantly sequential and will be discussed in their general order of occurrence.

Task 1: Refine Causal Loop Diagrams. This study design report includes causal loop diagrams for the major elements to be studied. The variables named are those deemed most necessary to a full appreciation of the interfaces among the five elements. Despite the desire for a high level of aggregation in order to maintain reasonable costs for this research, a few more variables and their linkages may prove necessary for model refinement. Insight to that refinement will be gained here by detailed examination of the direction and polarity of each link, as well as a written discussion

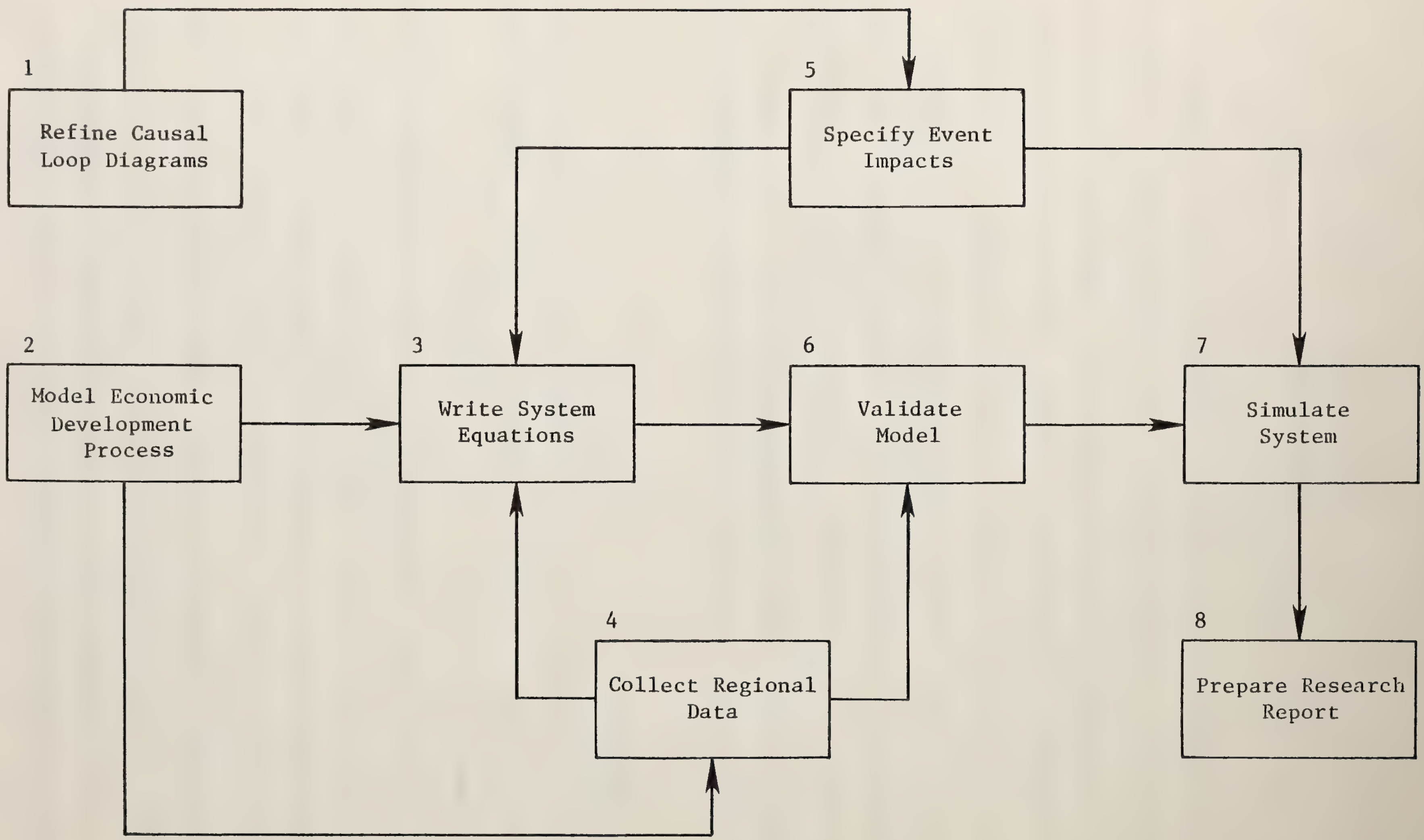

Figure 6. Study Flow for Innovative Research on Transportation Interactions with Society

of the stability of all feedback loops. This task will be used to inspire final event selection and as the basis for formal modeling procedures.

Task 2: Model Economic Development Process. The purpose of this task is to translate the causal loop diagrams into formal flow diagrams for computer implementation. This will be accomplished in two steps: complete definition of the variables and computer flow charting of every relationship. Variables will be defined by their dimensions and specified as either tangible or information. Then they will be categorized according to whether they are level, rate or auxiliary variables. Level variables are those which describe the state of the system and represent the results of accumulation or integration. Rate variables represent decisions, actions, behavior or flows (of materials, money, people, equipment, orders, information or power). Auxiliary variables represent information inputs combined into concepts and will be used as input to rate decisions.

After the variables are completely defined, their relationships will be described by a formal flow diagram. This diagram will display unique symbols for not only each type of variable but also for each type of flow, including their sources and sinks beyond the system boundary. In addition, all constants will be displayed, as will third-order (any very long) delays thought to exist in the system. The results of this work help specify the exact type of data required by the model and designate the equations necessary for complete system description.

Task 3: Write System Equations. This will be, by far, the most challenging task of the study. On the one hand, a high level of aggregation is required to control cost of assembly and operation of the model. On the other hand, it will be easier for the analyst to discover or derive the estimating relationships for some of the causal loops at a very disaggregated

level and he will be inclined to do so. At this point in the research, however, every effort will be made to keep the model realistic yet simple. The equations will be written initially in algebra.

Levels in the system will be described with difference equations. The rate equations will be based on the system state. Auxiliary equations, written as functions of state and other auxiliary values, will be used to feed rate or other auxiliary equations. When no functional relationship can be found, auxiliary and rate equations will be approximated by tabular functions. Finally, the long time delays will be simulated using third-order delay functions. After the system of equations is complete, they will be implemented in a source language developed for system dynamics known as DYNAMO.

Task 4: Collect Regional Data. Availability of regional data was discussed earlier in this study design report. Because of the regional nature and high level of aggregation of the study, some difficulty may be encountered in the discovery and use of suitable secondary data sources. Therefore, every effort will be made to allow sufficient time for research. The contractor has, of course, been collecting data for similar work for a number of years. Should that resource and other data collection efforts fail, selective development of primary data is possible because the contractor is located within the region recommended for study. A travel budget has been estimated to cover that eventuality. If, for some reason no data seem satisfactory for certain estimating relationships, the study design is robust in that judgments are introduced easily. Those judgments will be drawn from the contractor's multidisciplinary staff and fully documented. Data and judgments will be used to calibrate and validate the model.

Task 5: Specify Event Impacts. A set of events was also discussed earlier for potential inclusion in the study. This set will be modified as dictated by the refined causal loop diagrams and adjusted to include historical events for model calibration and no more than twenty unprecedented events for system simulation.

It is, of course, this set of events which makes the system dynamics model probabilistic. The events are connected to the model by way of more loops and cause the continuous system to become discrete. The event set effectively will include trend events, discrete events and policy levers. As mentioned before, the event impacts will be estimated on three levels: event on event, event on model, and model on event.

Task 6: Validate Model. Validation of dynamic models is difficult, especially when they incorporate random events. Three approaches may be taken, the first two of which are recommended: 1) replication of history over a time span not used to calibrate the model, 2) tests for correct response to imposed conditions, and 3) examination of the fidelity of the forecast. The last option unfortunately presumes the luxury of time.

In the first two approaches, the random events will be set at probability zero. Then the simulation model will be run and the output checked against known regional trends discovered in Task 4. Naturally, if something is found not to conform to reality or is such a counter-intuitive response as to be nonsensical, the system equations will be recalibrated or rewritten.

Task 7: Simulate System. Once confidence is gained in the model, the probabilities will be set to reflect the contractor's best estimate of likelihood for unprecedented events and the model will be run. This is accomplished by selecting an efficient time interval for this sychronous

simulation and then running until stability is found in the variables or until a reasonable time span for the forecast has been covered, say, twenty years. Because of the stochastic nature of the model, it will be necessary to make a number of runs in order to establish confidence limits on the output variables (where one output variable could be growth in business investment).

This procedure must be repeated for each change in study assumptions (e.g., level of public subsidy to the region's transportation investment). Obviously, a large number of computer runs are involved, but the changes are easily implemented. Control on computer time is accomplished by model simplicity resulting from a high level of aggregation. Experience has shown that it is better to keep the model simple and conduct a number of sensitivity runs than vice versa. It seems to be the most efficient way to discover whether large changes make no difference or small changes make a big difference in outcome.

Task 8: Prepare Research Report. This task addresses the ultimate objective of the research, i.e., improved understanding of transportation interactions with society. The sensitivity runs mentioned above will contribute to that understanding. Results of those runs will be documented here. Undoubtedly counterintuitive results will be observed. The model will be probed for underlying reasons.

In addition, all judgments and assumptions will be documented. Data of particular importance and/or of low quality will be highlighted. Complete listings of the computer program for operation on NCSS time-sharing services will be included as an appendix. Finally, recommendations for further research or applications will be made based on the opportunity to participate in this very interesting and important work.

Task and Program Schedule

A suggested schedule for completion of each of the tasks, and therefore the program, is shown in Figure 7. It is estimated that loop diagram refinement can be completed quickly so that detailed flow charting will be accomplished by the end of the second month, at which time a progress report will be rendered. The preparation of system equations will then commence and be ready for validation two months later. Another progress report seems appropriate here. If validation indicates a requirement for model modification, another month has been allowed. Data collection will begin about one month after flowcharting begins in order to support system equation writing. This will be a lengthy process because of possible data paucity and the requirement to interact with the validation procedure. Events must be specified in anticipation of model validation and will continue to be defined through the sixth month, at which time another progress report is rendered and system simulation begins. A month and one-half are scheduled for model validation, beginning in the fifth month. The last progress report will be rendered two months after a three-month system simulation has commenced and then final report writing begins. The draft final report will be delivered at the end of the tenth month for sponsor review and the program will be completed in twelve months with delivery of the final report.

Personnel Allocation

The allocation of professional manpower by task by month is shown in Table 3. Note that staffing is at a level of about one-and-one-half persons full time. However, the broad scope of this work demands a multidisciplinary study team of five. No need for consultants is anticipated. Resumes of the participants are included as an appendix.

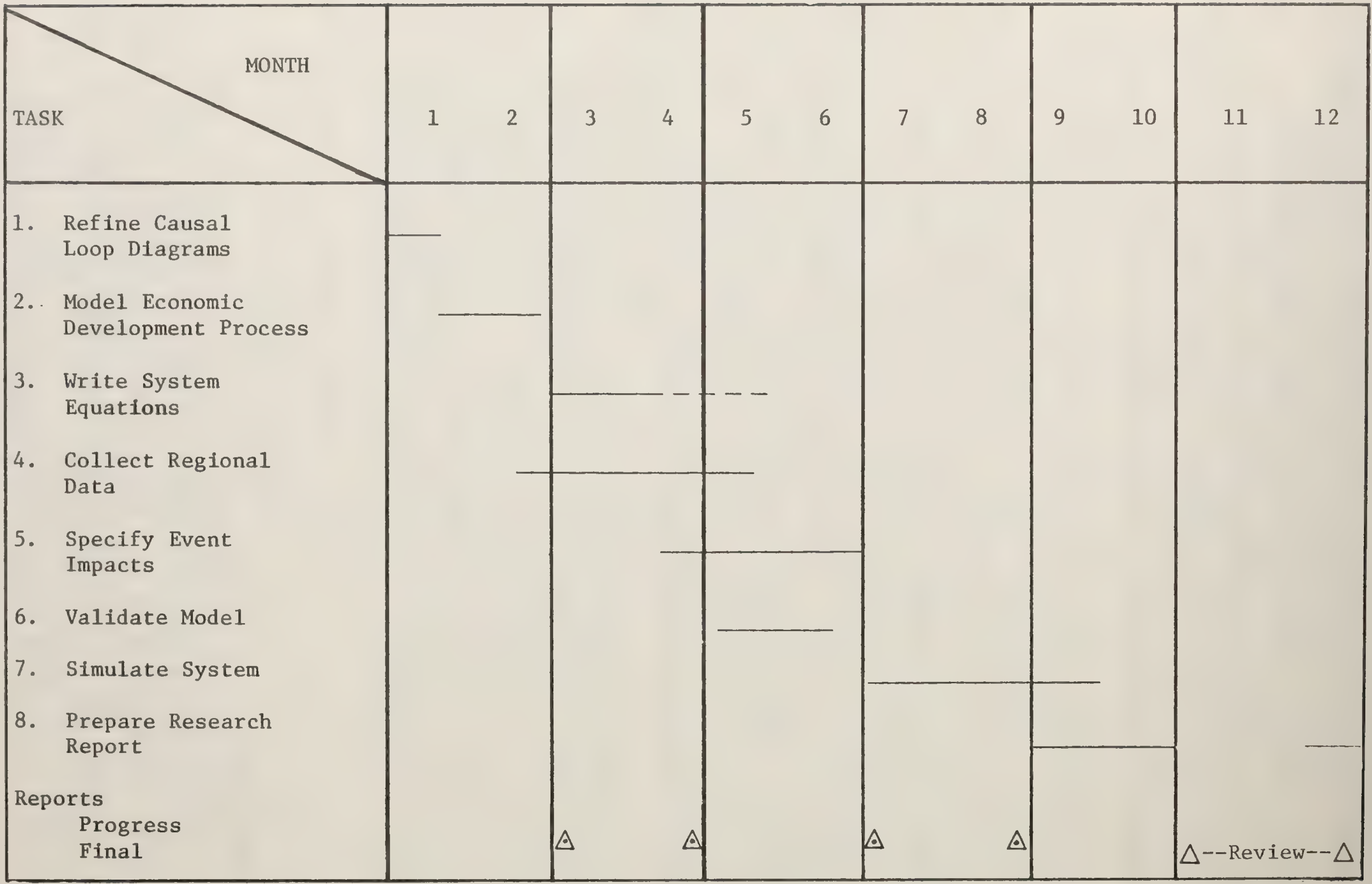

Figure 7. Interactions Study Schedule

Appendix A and pages B.1 and B.2 of Appendix B have been deleted.

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U.S. Dept. of Labor, Bureau of Labor Statistics, Employment and Earnings Statistics for States and Areas (Washington, DC, 1939-). Annual.

By state and major areas. Annual averages on payroll employment by industry; hours and earnings of production workers by industry; employment and earnings trends by region, state, and major area.

U.S. Dept. of Labor, Bureau of Labor Statistics, Handbook of Labor Statistics (Washington DC, 1924/26-). Irregular.

Prices and cost of living, earnings, hours, and wage rates, etc. Includes all major statistical series compiled by BLS. Latest edition: 1978.

Federal Communications Commission, Statistics of the Communications Industry in the U.S. (Washington DC, 1939-). Annual.

Financial and operating data on telephone, wire-telegraph, ocean-cable, and radiotelegraph carriers and controlling companies; employment and compensation; and numbers of telephones in homes, by states and by principal cities.

Federal Bureau of Investigation, Uniform Crime Reports for the United States (Washington DC, 1930-). Annual.

Data on crime trends, crime rate, public safety employment, and arrests.

U.S. National Center for Health Statistics (HEW/PHS), Vital Statistics of the United States (Washington, DC, 1937-). Annual.

Covers matters of life, health and welfare. Reports on birth and death registrations, causes of death, incidence of specified diseases; marriage and divorce, etc.

Helen Axel, ed., A Guide to Consumer Markets (NY, The Conference Board, 1965-). Annual.

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Book of the States (Lexington, Ky., Council of State Governments, 1935-). Biennial.

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U.S. Dept. of the Interior, Bureau of Mines, Minerals Yearbook (Washington, DC, 1932-). Annual.

Mining and minerals activity, economic and technological developments and trends; metals, minerals, and fuels; and domestic area reports.

International City Managers' Association, Municipal Yearbook (Washington, DC, 1934-). Annual.

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- U.S. Census of Population
- U.S. Census of Business
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- Government Finances
- City Government Finances

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- Monthly Labor Review
- Union Wages and Hours
- Injury Rates by Industry
- Scientific and Technical Personnel in Industry

Interstate Commerce Commission (Washington, DC):

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APPENDIX C

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. A probabilistic systems dynamics approach was introduced as a means for simulating the interaction of passengers and freight transportation systems with key social and economic factors.

Micro-Economic Model

A STUDY DESIGN FOR FURTHER DEVELOPMENT OF A POLICY SENSITIVE MICRO-SIMULATION MODEL OF AN URBAN ECONOMY INCLUDING A TRANSPORTATION SECTOR

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STUDY DESIGN REPORT

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1.0 PROBLEM STATEMENT

It is essential that transportation investments be based on a complete accounting of benefits and costs. Increased attention must be given to indirect benefits and costs because of their growing importance in transportation decision-making. What is required then is a holistic approach which relates transportation investments to other sectors of the economy. Specifically, the urban economy should be modeled in such a way that changes in various sectors can be analyzed in various combinations, or even singly.

Having such a model will enable decision-makers to know more about social and economic impacts of programs and policies and projects in transportation. The question of which alternatives to pursue will remain in the hands of policy makers. A model of the urban economy with transportation as an explicit sector related to all other sectors will enable transportation policy makers to make more informed decisions.

2.0 UNDERSTANDING THE PROBLEM

Large amounts of research and development have been performed on urban transportation problems. Most of the work has been carried out in a partial context, although significant amounts of work have produced some results in relating transportation to overall urban development. Enough work has been done and enough problems have been faced to produce a general recognition that there is a complex interdependence between the several levels of public decision-making and the vast amount of atomized decision-making of firms, households, and individuals in the private sector. Some means of properly abstracting these interdependencies in a manageable and sufficiently specific way would provide both public and private decision-makers with an enormously useful tool. It is this recognition that led to the research already done on transportation and urban development.

Most attention has been given to land use/transportation interactions in past research. Both theoretical and empirical study approaches were undertaken and both types of models have emerged. However, most approaches still are incomplete in one way or another. For example, there is a general lack of consideration given to how housing markets, local production and trade activities and external trade activities interact with each other to produce decisions on levels of transportation services and facilities. Furthermore, work

to date has not adequately allowed an analysis of how intergovernmental public decision-making and investments in transportation change relative efficiencies in an urban economy, viewed as an income producing and distributing unit.

Shortcomings of the state of knowledge and faults in research design could be recited in some length. Suffice it to say that an adequate model which is both comprehensive enough to be complete, and concise enough to be doable, does not exist. Lack of a standard approach in the literature and profession and the current TSC search for innovative approaches both attest to this fact.

In summary what is needed is an approach which incorporates both a firm theoretical structure and basis, with empirical findings. Also a multi-sectoral approach is required to recognize all the major activities transportation affects directly or indirectly. We propose such an approach. Considerable development work has already been done. Important research lessons from previous research efforts have been incorporated in our model. This means that unlike most previous urban models, ours does not attempt to construct theory "from the ground up". Rather, our model provides a framework whereby existing theories and findings, including those embodied in previously developed models, may be incorporated.

3.0 TECHNICAL APPROACH

3.1 Introduction

It is proposed to implement the first level of a microsimulation model of the urban economy. The elements of a framework for such a model have been incorporated in Appendices to this report as follows:

- the equations constituting the model, together with the assumptions underlying them, and consideration of possible alternatives and extensions (Appendix A);
- system characteristics and requirements (Appendix B);
- specification of the modules (Appendix C).

The principal author of this initial framework, Dr. Irving R. Silver, is to be the principal investigator in work which would ensue as the result of any modification(s) of the present contract.

The rationale and structure of the model are discussed in detail in the Appendices. The basic equation structure for the entire model is fairly compact. There are separate equation sets for the following activities:

Social Utility

Regulatory Constraints

Public Revenue

Public Service Budget

Transportation

Housing Market

Production

Consumption

Wages and Prices

Land Market

In sum, these describe an urban economy. The model incorporates adjustment processes in the individual markets. Many variables are common to two or more equation sets and lagged variables are included. It is an allocation model in the sense that activity levels in zones which sum to the urban region are estimated by the model. Levels of population and basic industry are established first and entered in the model.

The model is by no means large scale or impractical. Development work to date on the model has been geared toward producing a useful, theoretically sound, testable and implementable policy-sensitive analytic tool. Once in place with data for a representative urban area, the model is capable of tracing through, over time, the effects of transportation investments on the other major sectors of an urban economy. The model will also estimate the effects of non-transportation investments or regulatory actions on transportation.

This is an innovative model, building on results of past model development and research. Many of the less important relationships indicated in past studies have been dropped from the proposed model, while important relationships have been combined and aggregated, to the maximum extent possible, given analytic needs to output specific data items.

The most innovative feature of the model as contrasted with other urban simulation models, is its market clearing mechanism which relates all the sectors with each other. It is fundamentally an economic model. The following sections of this Proposal consist of excerpts and a summary of the most pertinent sections of the report. Citations to some related studies are included in the General References in Appendix G.

3.2 Main Features of the Model

In consideration of the objectives stated by TSC, the following are the features of the proposed work which appear to be of greatest significance.

First, by treating the market for transportation within the context of an elaborated set of economic relationships, a wide variety of public policies and actions may be investigated which affect transportation, sometimes in indirect and possibly counter-intuitive ways.

Second, the development of this model would produce an investigative tool which may be employed to examine the implications of various theories and empirical findings related to the spatial arrangement of activities within urban areas under a wide range of conditions in the urban economy. The model would simulate the effects of behavior related to the findings of other investigators in a multi-sectoral context. It would not itself be employed to derive theoretical propositions, but would synthesize disparate research

findings.

The model is to be operated as a heuristic device, i.e., one by which the accumulated understanding, as well as conjecture about the workings, of the land market and its relationship to transportation can be incorporated in a coherent way. Operationally, the necessary flexibility for achieving these aims is to be achieved by structuring the model as a set of modules. These may be given alternative specifications, and their linkages rearranged to represent, respectively, alternative behavioral hypotheses and causal sequences.

Third, the model depicts the urban economy in terms of an interrelated set of markets. The spatial arrangement of activities pertaining to those markets is determined through the land markets -- the market for location and areal extent of occupancy by activities.

In its broadest interpretation, the urban land market encompasses a host of phenomena, which are the subject of a wide variety of partial urban studies, including those of the relationships of transportation and land use, industrial location, retail markets, housing and land use control. Analytical models of the land market, however, have been rare and extremely simplified. Component markets, other than the one for location, have been treated particularly naively in such models.

3.3 Stages in Development and Objectives of the First Stage

The model as specified in succeeding sections of this report, while it is self-contained, is viewed as being the first stage of a development which would see subsequent modifications and refinements in the form of greater elaborations of the behavioral equations, of the data employed in model simulation, and of the computational system, including devices for greater user-orientation. While all of the components of the model necessarily include simplifications about the workings of the urban system, it is asserted that the most significant interrelationships have been captured in the series of markets which constitute the model. Nevertheless, it seems inevitable that as the model is used it will be desired to elaborate one or another component or set of relationships among components of the model. The desire for such change will likely arise, most commonly, because of the need for greater specificity in the outputs of the model, and/or greater sensitivity to policy instruments of a specific form. Another, though less likely, reason for wanting to extend the model beyond its initial formulation would be to incorporate either important new developments affecting urban growth, e.g., changes in technology, or new research findings, e.g., based on extensive surveys, or other new data.

We are proposing an heuristic approach to the de-

velopment of the model, and this is reflected in two aspects of the project. First, the model itself is structured as a series of modules. It is anticipated that ultimately the computational system underlying the model will allow for replacement of individual modules by equations and algorithms representing alternative hypotheses about how the individual markets which constitute the urban economy function. Such substitution will, in the initial version, be possible to only a limited extent. Second, the project would include a period for training and initial simulations with UMTA-TSC staff who would ultimately be responsible for design, running and interpretation of model simulations. Out of this phase would come recommendations for modifications to render the model adequate for operational use in the medium term. In advance of this client feedback, however, there is included in the project an allocation of resources for studying, and, if possible, implementing revisions to the transportation module as it is now designed. While it is felt that this module captures the essential features of the transportation system and transportation behavior as they relate to other components of the overall urban system, it may be possible to give greater elaboration to this and related modules without a major restructuring of the model. Such elaboration might include explicit mode choice, a differentiated transportation network, etc.

The objectives of the first stage of development may be summarized as:

- first, the development of a workable system for simulating arrangements of scenarios consistent with policy and other exogenous alternatives;
- second, the identification of the properties of the model as a working system;
- third, to demonstrate that the model is capable of yielding results useful to the client.

The model, as originally specified, is very rich in simulation possibilities as will be demonstrated in a later section. It is felt that in its present level of specification, the model strikes an appropriate balance between realism, i.e., a sufficient amount of elaboration to correspond with real-world situations to be dealt with by the user, and on the other hand, need for manageability of the computational system.

The objective of developing a workable system has been dealt with in three respects. First, in terms of system development, the approach which we intend to implement and establish is a core of optimization modules which become a central driving force of the model. This core includes the allocation of consumer and public sector

budgets and might also incorporate specific markets such as those for housing, location and transportation. A number of other modules, each corresponding essentially with a single or a set of input/output relationships represented by equation sets, are used to feed these basic optimizing mechanisms. This strategy, it is felt, would lead much more rapidly to convergence to stable outcomes within tolerable intervals. In other words, there is a considerable problem, in complex systems such as the one presented in the model, of such erratic shifts between iterations in the simulation that no valid conclusions can be drawn of the ultimate values of variables when the system reaches stability. We have adopted an approach which we feel maximizes the probability that such stability will be achieved without an inordinate amount of computation. Further description of the proposed system is included in Section 3.4. The capture of data at a level of micro detail implied by the model equations represents a second aspect of system development. The problems have, to a considerable extent, been circumvented by the use of the device of examining an urban area with composite characteristics, i.e, one which typifies the distributions of characteristics to be found in an "average" urban area. This approach allows simulation in the first stage from which generalizations can be drawn for most urban areas. Furthermore, it is consistent with the objective of

providing a device for strategic policy evaluation rather than a planning tool for individual urban areas. Greater precision could be achieved, and comparisons of impact of a variety of policy and exogenous changes evaluated, as to their differences among types of urban areas if a set of "model" urban areas were represented in the data base as part of a later project. A survey of data sources for the model variables is presented in Appendix E. These data are derived for the most part from standard sources, and we perceive no significant problems in assembling such information and incorporating it in the data base.

The second major objective of the first phase is to identify the properties of the model as a working system. This involves first, the examination of:

- the stability properties of the model as well as its sensitivity to alterations in the hypotheses embodied in the model, i.e., the formulation of the equations and their interrelationships in the overall solution;

- variations in speed and extent of behavioral reactions, i.e., the parameters of the system;

- the levels of both exogenous variables and initial starting values for endogenous variables.

Second is the question of ease of use of the model. The model, even in its initial form, has the potential for a wide

range of investigations, as will be illustrated by several examples in Section 3.5. Intelligent use of the model, however, requires an investment of the user's time in understanding the behavioral relationships, both included explicitly and assumed in the construction of the model. It would seem imperative, therefore, that a period of familiarization and trial operation of the model be incorporated into the project. Such trial operation would also have the advantage of identifying modifications to the software to be developed to facilitate its use and render the outputs easier to interpret.

Third, while there is in concept the potential for posing a large number of alternatives about urban growth, policy, etc., the mechanics of constructing alternative simulations may be facilitated by the existence of a set of structures, each embodying a particular base case.

These structures would include variants on disaggregation of variables, and on the operation of specific constraints, so as to include the particular features of the economy of most relevance.

As a third major objective the model must, of course, be capable of yielding useful results for the client, if it is to be more than a research tool. There are two aspects to this point. First, the simulations must be plausible. This means that they must be built not only on real-world data but also (a) that the model equations and optimizing routines

reflect the essential characteristics of the markets which they represent and (b) that the model parameters be accurate. The behavioral relationships are based on models which have been employed in research studies in urban economics and other micro economic topics. While a direct translation from the parameters evaluated in partial research studies available in the literature is not usually possible, because of the specific assumptions and clarifications used, it will be attempted to employ ranges of values which reflect research findings where they are available. For each of the individual modules substantial numbers of studies are available for this purpose. A sampling of such studies, together with a brief abstract of each is shown in Appendix F. There remain a number of "invisibles" or abstractions particularly in the matter of utilities and attributes, the evaluation of which is possible only through some type of inference. The settings on the values of the corresponding parameters, which must be judgmental, can be tested for their plausibility only by examining how well the output levels of the model simulated as a whole corresponds with what might be identified as long run levels in actual urban areas. In this respect, the construction of a composite urban area, containing values representative of U.S. urban areas as a whole is helpful. At the same time, it has to be stressed that the use of such abstractions limits the application of the model to one of predicting generalized

outcomes. The advantages of use of these abstract measures, which will be discussed further in Section 3.5, are felt to outweigh this disadvantage. Finally, in order for the results of these simulations of an idealized urban economy to be plausible enough, so that U.M.T.A. is willing to apply the conclusions with confidence to the real world, it is necessary, as a practical matter, to be able to test the results. While observations of actual urban areas reflect a host of short run changes which complicate comparison with model results, it is suggested that historical growths of individual urban areas, as well as cross-sectional comparisons of the urban areas, of different sizes and characteristics at a point in time could be used to validate the model. The second aspect in the consideration of the usefulness of the results of the model is the question of whether it enables UMTA to perform simulations and derive conclusions which are relevant for the problems with which it is faced. We shall outline in Section 3.5 several types of scenarios in which UMTA might employ the model for guidance in policy considerations. These or other scenarios might be employed in a series of trial simulations with the model in the course of the project, the choice of scenarios depending upon discussions between the builders and the clients.

As stressed at the beginning of this section, the development strategy for the model is based upon providing

a capability for adding on to, or modifying the basic model in ways which enhance its capability to deal with the problems specifically of concern to UMTA. Such extension might involve endognization of particular relationships initially treated exogenously, greater disaggragation of specific variables, etc. Within the project being proposed it is intended to study the transportation module with a view to further elaboration. This is not to preclude the possibility, however, that as a result of operation with the model, other aspects may not be recognized as having greater priority. It should be cautioned that the modularity feature of the model is limited in the initial stage of development by the other requirements outlined above in building, testing and trial operation with a system in a relatively short period of time.

3.4 Structure of the Model

3.4.1 Overview. The approach of the model is micro-analytic. The structure of the model involves a variety of actors. These are primarily households, firms, and the local public body. In the initial version of the model there is only one local public body. In future versions, it is anticipated that several such bodies would be represented, reflecting the multiplicity of jurisdictions typically found in large metropolitan areas. Higher-level governments' actions are represented by activities entered exogenously and by fiscal transfers dependent upon the local government's

spending. Both in the initial version and subsequently there would be a number of households and of firms with distributions of characteristics such that it would be possible to generate a variety of behavior patterns, e.g., different firms would not only produce different goods but would have production functions sufficiently different, that we could observe some of them being primarily exporters of finished products and employing local factors and materials, others importing factors for production of goods sold locally, etc. Each group of actors would perform according to some explicit model. In general, the system would behave on the basis of decentralized decision-making with the local public body attempting, at least initially, to avoid distributional extremes. While each actor or group of actors (given appropriate aggregation procedures) will act according to some specific optimizing program, the overall model will not seek an optimum optimorum. It would be possible, however, to run the model with different sequences and with different speeds of adjustment for the individual components and to examine the sensitivity of the result.

The three types of actors are involved in a series of markets which serve to set prices which then become signals for behavior in the succeeding period. These markets include the following:

a. Commodities: This category includes both

intermediate and finished products. All commodities are non-durable, i.e., they are produced/imported and consumed/exported in each period in their entirety. No stocks or physical plant are carried over.

b. Housing: Because of the importance of housing in the urban land market due to its essential connection with residential location and with the transportation system and the consumption of urban land, the housing market is treated as an entity in some respects separate from the commodities market.

c. Public Services: These include both the traditional services provided by the public body acting as a production entity, e.g., transportation, and other services associated with the control function of government, e.g., amenities which result from the modification of externalities arising from the spatial proximity of urban activities.

d. Private Services: Besides the services normally provided by the private sector, this category might also include some of those normally associated with the public sector. It is desired to examine relative efficiency of provision through the private and public sectors.

e. Labor: The function of the labor market is to set a price for the services of labor such that laborers spatially-distributed by residence would be allocated to a spatially-distributed set of firms and the public sector.

f. Land: Land values are derived from the activities in all of the above markets which take place upon the land.

One of the guiding principles in the construction of the model has been to allow a high degree of flexibility in the introduction of hypotheses about the individual types of agents whose actions affect the urban land market. This flexibility is necessary if the model is to serve the objective of providing a tool of investigation for urban transportation-related research. For any specific version of the model, this flexibility is limited by the degree of detail of the data set upon which the computations are performed, and by the capacity of the computational system which is employed. These constraints in turn imply first, that considerable foresight be used in the design of the data base so as to reflect the kinds of hypotheses which will subsequently be examined, and second, that a suitable software system be available. In order to achieve this flexibility, moreover, the urban area which is to be simulated is represented, in the first phase of model development, by a generalized set of activities and idealized distribution of those activities and by an idealized transportation network. Besides simplifying much of the computation which will need to be made in the simulation and the treatment of the fictional idealized urban area, this approach also simplifies the problems of data

availability and accuracy, while at the same time, for purposes of future empirical work, it will demonstrate the kinds of data which will need to be collected. More realistic representations of these components could be incorporated without major restructuring of the original system, to expand the potential for simulation and eventual application to actual urban areas. The Study Design work will consider limitations imposed by real world data.

The initial version of the model produces a long-run solution. Through a series of iterations, an outcome is achieved which represents complete adjustment by all actors in the economy of production, consumption, price and location decisions consequent on the combination of levels of exogenous variables fed into the system in each period. Growth over time can be simulated by a series of one-period adjustments to changes in the values of these exogenous variables, e.g., growth in size and change in composition of the population. As with the specification of activities, so too with the adjustment properties of the model, more realistic assumptions, reflecting dynamic behavior, can be introduced later. This modification would be accomplished by internally reformulating any or all of the system's modules.

3.4.2 Issues in system design and development. In adapting a model such as the present one which contains an interrelated set of behavioral equations to a specific compu-

tational system, a number of issues need to be resolved by the model builders. These issues, almost inevitably, involve not only decisions among alternative computational methods for implementing the behavioral relationships as formulated, but also some refinement and possibly re-specification of the form which those relationships take. The project under discussion is expected to adhere to this generalization.

The issues which will have to be faced and resolved by the model builders in the process of systems design and implementation involve a hierarchy of considerations. First, and most generally, is the question of the extent to which optimization models would be employed in alligning the various markets which constitute the model structure, versus the use of heuristic devices whereby parameter and other adjustments can be made so as to obtain stable and reasonable results. In general, the application of optimization models has the advantage of forcing consistency in the solutions and reducing the arbitrariness involved in obtaining them. In other words, non-optimization procedures may allow a large number of solutions among which a choice of the single most plausible would be difficult, if not impossible. On the other hand, the attainment of flexibility in introducing alternative hypotheses can most easily be achieved by a set of individual solutions of parts of the system with a minimum of forced consistency among those parts.

From this general problem stems the subsidiary one of the general form of the structure of the model -- briefly, at one extreme a general-equilibrium solution in which ratios of marginal utilities to prices are equalized, versus a decentralized system of markets and quasi-market allocation mechanisms in which a stable solution is possible essentially because the components of the system are only partially linked.

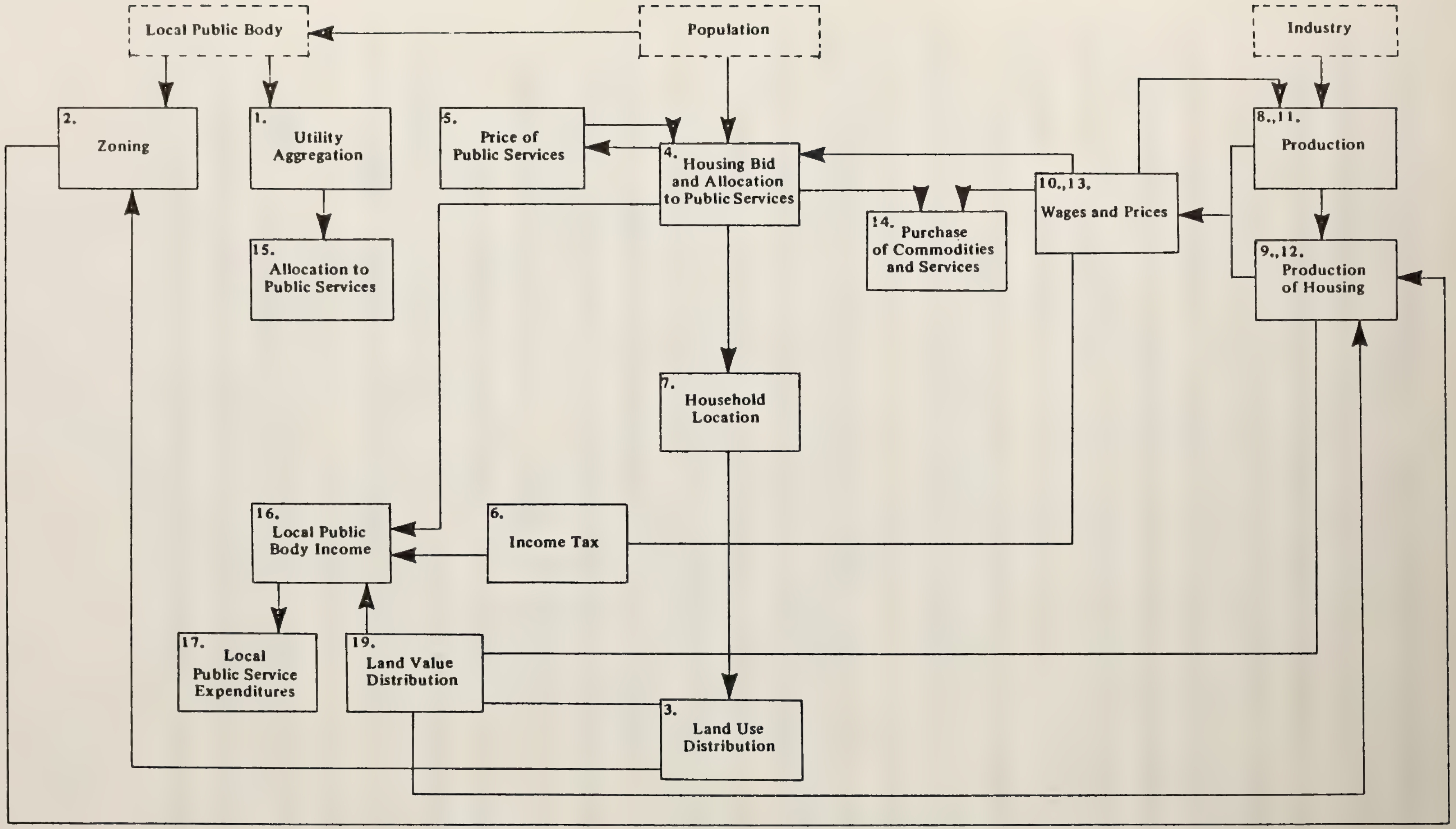
Considering this general problem in the context of the specific model with which we are dealing, we shall discuss, in Section 3.4.3, an initial specification in which market and other allocation mechanisms are presented as a series of modules to be run primarily recursively, with some amount of feedback and adjustment. In Section 3.4.4, we shall outline an approach for regrouping the modules in order to move somewhat toward a general-equilibrium solution.

A specific formulation which will be chosen in the course of the work on the implementation project involves a choice as to the relative extent to which one of two solution methods is to be employed. If the initial logical-flow of the solution of modules (as presented in Section 3.4.3) were to be strictly adhered to, the system would involve a combination of separate optimizations of consumer and public sector budgets, together with a set of individual market adjustments, the latter entailing parameter adjustments for

achieving stability of the solution. Alternatively, as outlined in Section 3.4.4, there would be a mathematical program involving, at the core of the computational system, a decomposition algorithm which would be related to blocks of generation and updating modules. This latter approach would make it possible both to achieve efficiencies in computation through attainment of convergence, and, through the generation of shadow prices -- a concomitant of the mathematical programming solution -- to endogenize the calculation of many of the parameters which would need to be set externally in the other approach.

The design of a specific solution method would involve a number of subsidiary issues which would occupy the model builders in the early phases of the project. These would include: the extent of hard-coding of parameters, implying a trade-off between computational efficiency and cost, on the one hand, and flexibility in introducing alternative research results on the other. A second consideration would be whether the model should be structured so as to allow changes in the data from run-to-run versus building in such changes (via updating) from period-to-period within a simulation run.

3.4.3 <u>The model system -- an initial view</u>. The accompanying chart shows schematically the various computational modules which comprise the model in its initial



Schematic Diagram of Model Structure

version and their basic interaction. The intent of this section is to specify in general terms the kind of interactions which take place between the modules in order that the reader may better understand the true dynamic nature of the model within a given iteration (for a given time period) of the model. The Appendix includes a more precise specification of each module, including inputs and outputs.

The initial module is the aggregate of the utility functions of the population for the formation of the local public body. It is assumed that within each physical district or zone the population aggregates its utility for the various public service attributes and that it elects a representative who reflects the average utility in these public service attributes. The representative's utility function is therefore a direct representation of the characteristics of the aggregate of that particular population zone. This utility function refers not only to the attributes of public services, such as criminal justice, health and welfare, sewage and water, and education, but also to certain regulations, particularly zoning regulations. It is necessary also to have a module which actually calculates the utility for zoning regulations themselves (module 2). The parameters of this utility function depend upon the existing distribution of the land percentage division between different utilizations of the urban land (module 3). The breakdown of these

utilizations is residential, commercial, industrial, transportation, public services, and private services. Thus, the first three modules are basically concerned with deriving utility functions for the representative as a function of the utilities of the resident population of a particular physical zone.

The fourth sub-module is the population's housing bid and its allocation to public services. The population is assumed to perform an optimization in terms of its allocation between public services, private goods, private services and housing. Once the allocation to public services has been made it is then possible to derive the corresponding tax base which would be needed to supply this level of expenditures in the public services. This implies a certain property tax rate for various parts of the urban population or the land. In addition, the portion of the public body revenue resulting from inter-governmental transfers is calculated (Module 6). From the allocation to public services, it is also possible to derive a price of public services as a function of the public service type and the sector to which it is delivered (Module 5). From this module also we can derive the housing bid of a particular group of the population (population is classified by age, occupation type, skill level and family size). This housing bid then becomes part of the input to the household location module (Module 7) which, via a bidding

algorithm, locates certain families according to the supply of housing which has been generated by industry for that particular iteration. In the present version of the model, it is assumed that housing is reproduced for every iteration of the model.

Module 8 derives the projected industry production and demand for input commodities and services by initially performing a derivation of change in production level as a proportion of change in previous price levels. This projected production of industry includes in Module 9 the projected housing industry production of new housing.

From these projected production levels for both the private non-housing industry and the housing industry, it is possible using simple functional relationships to derive the predicted wage and price levels in the economy for labor and for the commodities which are produced. This prediction is done in Module 10. Having determined the wage and price prediction, it is then possible to make a final determination of the industry production of commodities and of new housing using basically the same modules as previously, but with the new wage and price levels, in Modules 11 and 12. This then determines a new set of price and wage levels (Module 13). Given that we now have a production of housing with certain wages and prices, it is possible to use the algorithm of Module 4 to derive the population's choice of commodities

and services, given their housing choice. This is done in Module 14, and consists of re-running the optimization which was performed in Module 4. Having finally derived the housing and private goods and public services choice of the different population sectors, it is then possible to derive an aggregate utility function for the local public body by aggregating the different utility functions of the representatives and from these to make allocations to the different public services in order to maximize the utility of the local public body. This maximization is done in Module 15. Naturally, an input to the local public body's optimization is its income which is derived as a function of federal and state grants derived from local income tax revenues as well as property tax using the property tax rate which is derived earlier in Module 5. The derivation of local public body income is performed in Module 16. Given a certain level of expenditures in the different services by the local public body, within each service it is then possible to make an expenditure to each part of the service or in each physical sector in which the service is delivered. This, again, is done on the utility constraints of total revenue and the delivery of services representing minimum attribute levels to the different zones of the urban area.

By using the distribution of the population and the distribution of the work places, it is possible to derive

transport system utilization and the cost of transportation for particular individuals in Module 18. This then not only gives the cost of transportation to particular population groups, but includes congestion costs given the present location or distribution of activities in the area.

Land value in each sector and for each zone size is set (Module 19) as a function of a distributed lag of value for that class in previous periods and the discrepancy between offer price and market price of housing located in zones of that class in the preceding period.

3.4.4 Model system -- structure for computation -- Reorganization of the model. The model described in Section 3.4.3 comprises nineteen separate but related modules. For the purposes of theoretical clarity and computational efficiency, it would be advantageous to restructure the model by grouping and aggregating these modules into three major modules, as follows:

- A generation module, which would generate at each period the numerical structures necessary for the optimization module;
- An optimization module which would carry out the maximization of public and individual utilities at each period;
- An updating module, which would update model parameters from period to period according to whatever relationships are deemed appropriate.

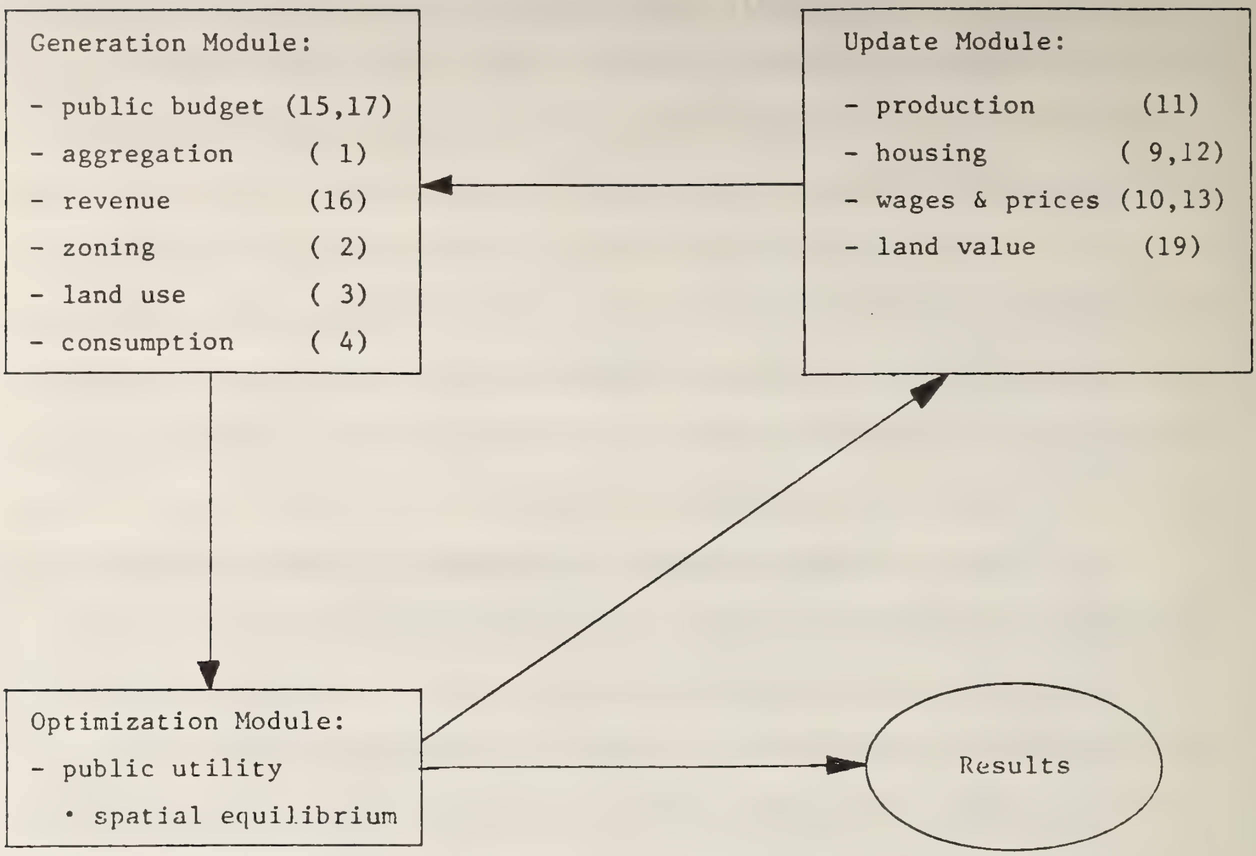


Figure 2

INTERACTION OF MODEL MODULES

There are several advantages to this structuring:

- The original modules are grouped and aggregated according to their general purpose;
- By placing the optimization at the core of the model (see below) with the remaining modules in a subsidiary role, it assures computational efficiency and convergence of the model at each period;
- As described in Appendix B, it permits an explicit, hierarchical structuring of the relations between the parts and the whole of the optimization module. This facilitates interpretation of results and modifications to the model.

3.5 Illustrative Applications

3.5.1 Introduction: Role of the model in policy analysis.

The model is viewed as potentially assisting UMTA in its policy analysis as an element of its long term strategic planning. It is designed to examine major questions as to alternatives available or potentially available to UMTA, and to the impact on the efficacy of its policy instruments as the result of environmental changes. These changes might be in the features of urban growth or in other public policies which have cross-effects on UMTA policies. Some of the recurring questions which UMTA seems likely to address with the model include:

- Financing
  - level of funding for transportation
  - alternative formulas for funding
  - balance between capital investment and operating funds
  - distribution of funds among urban areas by size, region, socio-economic characteristics, fiscal capacity, etc.

- The cross-impact of other Federal and State programs, including:
  - housing subsidies
  - public facility grants
  - general revenue sharing
  - employment-related programs
- Technological change
  - substitutes for transportation
  - plant size and location
  - industry mix and input requirements
- Demand determinants
  - household sizes and incomes
  - labor force participation rates and leisure
  - work scheduling over the day

In addition to the above questions which may be assumed as part of the routine policy analysis activity of UMTA, the model would allow the examination of many new problems affecting transportation as they arise, such as changes in labor force participation, price inflation in housing, technological change, etc.

In the following pages, we present several illustrations of applications which might be made of the model in investigating specific policy problems. It must be cautioned, however, that the model would not, even in later stages of development, produce "push button" solutions. Setting up, running and interpreting simulations meaningfully will require a thorough understanding of the model, the assumptions upon which it is based and the limitations which these impose upon the interpretation of results.

3.5.2 Scenario 1 -- Policy Studies: Changes in Financing Rates and Formulas

1. General

Inter-governmental financing plays a central role in much of federal urban policy, relating as it does to the degree of direction which the federal government will impose on urban spatial growth patterns, on the redistribution of income, and on the growth in the urban economic base.

In the area of effects of transportation decisions on urban economic levels and conditions, inter-governmental transportation grants are critical in determining travel patterns by mode within urban areas. They also influence, via feedbacks in the urban land market, the pattern of land use and distribution of activities within the urban area. More generally, if the local transportation system is seen as a necessary input to production in the urban economy, the physical configuration and utilization of that network is influenced significantly by capital and operating expenditures and their allocation by mode and type of facility. In brief, the role of U.S. DOT in the design of financing may be much more significant than its role in the design of physical facilities. Viewed in this way, i.e., is a problem in allocation of funds, the question then becomes: how is this allocation to be made so as to maximize income growth while achieving a desirable distribution of income. The trend in

federal legislation over the past decade has been toward allowing greater leeway for states and urban and regional governments and authorities to allocate resources among modes and as between capital and operating expenditures.

2. Model Features

A substantial part of the model is devoted to the allocation of the local public body income as among public services, including mass transportation. On the revenue side, specific terms are included in the equations to account for inter-governmental transfers from state and local governments. The equations are structured so that either specific sectoral transfers or general income transfers may be included.

3. Simulation with Model

Assume it is desired to examine the impacts on the urban area of an increased level of transportation funding flowing from the federal level. If the funding is specific to mass transportation, it would be entered in the local public body income equation (Module 16). The increased local revenues would be reflected in increased local expenditures on mass transportation; however, these increased expenditures would be offset to some extent by substitutions in the local public body expenditures in favor of other objectives. In a sense, local funds are "freed up" to be devoted to other types of public service. On the other hand, higher minimum standards of transportation may be introduced (Module 17) at the

same time reflecting either increased local aspirations respecting mobility as a result of the increased resources, or simply reflecting mandatory minimum levels required by UMTA as a quid- pro-quo for such funds. Depending on where these minima are set, the local public body may actually increase the allocation from its self-generated funds to mass transportation. Different formulas regarding the mix between capital and operating grants could be reflected, in the model, in the mix between inputs to the public sector production of mass transportation services -- capital construction and acquisition being heavily weighted by "materials" and operation being more labor-oriented. Further impacts may be traced on both the input and output sides of the local public body production function. A straightforward application of the model as formulated would demonstrate that the "cheaper" (in the sense that part of the costs are being borne elsewhere) mass transportation services would lead, via feedbacks through the population's utility functions, to a greater allocation of their budgets to the public sector. In addition, there may be direct substitutions between consumers' levels of mass transportation and goods provided in the private markets, insofar as the two classes of goods have attributes in common. Most significant here would be the substitution between mass transportation and use of the private automobile. There would also be further feedbacks

resulting from the effect on network loading through to location decisions of households in the housing market (Module 7).

Some additional results could be obtained by changes in data matrixes. By changing the cost matrix for transportation to reflect data on household expenditures on transportation resulting from a differential shift to mass transportation, the impact on consumer expenditures by individual household type could be derived. Further, if assumptions were made as to the diversion of each population class by distance to work and the consequent loading of the network, transport facility utilization levels by geographic sector could be calculated.

On the input side, the effects on local employment could be examined. These consist first of direct effects in the form of public sector employment associated with a shift in the local public body allocation resulting from its additional income. An indirect effect would be the altered local government purchases and consequently employment in the production of other goods locally.

More generally, the impact on urban income through wages, adjusted to the altered cost of overcoming distance, and reflected in the price competitiveness of local production would be observed.

Some related simulations would include intergovernmental transfers in other sectors and general income transfers (block grants) as a supplement to local public body income.

For the former it would be possible to observe the indirect impacts, among other things, on transportation demand and the supply of mass transportation. For the latter, a positive effect would be observed on the demand for public services stemming from the increased income represented by the inter-governmental grants. There would be a negative or displacement effect, however, resulting from the substitution of private for public services. The same countervailing tendencies would also be in evidence for sectoral grants such as grants for mass transportation including, in the latter instance, the effect of higher incomes resulting from the inter-governmental transfers leading to lesser preference for mass transportation relative to use of the private automobile.

3.5.3 Scenario 2 -- Response to External Shocks: Energy Price Increases

1. General

It is felt that the rapid rise in the price of oil and other forms of energy will have a major impact on the form of urban areas and on the demand for transportation. While the rapid rise in energy prices has been in effect since 1973, it is likely that long-run adjustments are only beginning to be made and that the extent of these adjustments will be more apparent with the continued rise in relative energy prices and the acceptance by consumers of the per-

manence of high energy costs. Observations of adjustments to these higher prices such as have been made over the past seven years, therefore, may not be an accurate guide to the type and extent of adjustments to be made in the 1980's. For appropriate policy guidance therefore, it would be desirable to predict the full extent of these adjustments. From the point of view of transportation policy, it is desired to know what the extent of adjustment will be in several dimensions. First, in the short term, adjustments may be made, with the existing stock of capital goods, by altering patterns of consumption in terms of travel habits and the consumption of non-travel goods. Travel habits may be altered so as to reflect increased energy costs in any of several ways: travel avoidance, i.e., decreased or combined trip making or trips to closer destinations; reversion to less fuel intensive modes -- mass transportation or car pools; and travel during off-peak hours. The last of these leads to fuel conservation by the avoidance of congestion; however, much of the saving from travel avoidance is likely also to be in off-peak hours due to the discretionary nature of much of this off-peak travel, so that the distribution of trips weighted by fuel consumption over the day may be little altered, although its total magnitude may be decreased. Other savings which may involve relatively small amounts of capital investment fall under the heading of better management of the transportation system. There are a number of political and tehcnical prob-

lems involved in the various approaches to better transportation system management. In addition, the effective increase in the capacity of the transportation system implied by better management, insofar as it decreases the price of transportation as a result of decreases in congestion, leads to a partially offsetting increase in the demand for travel.

In the longer term, adjustments may be made in automobile consumption, in the mass transportation system and infrastructure for transportation, and in the pattern of urban land use which would tend to be conserving of energy. Lighter cars are being produced which will have significantly improved mileage characteristics, although a trade-off exists between this objective and the desire for lower levels of air pollution. The transportation network may be altered and in particular both the direct effects of higher fuel prices and the induced effect of residential settlement patterns would tend to push the demand for mass transportation above viable threshold levels; however, the long-run viability and efficiency of fixed forms of mass transportation systems will depend not only on the extent of concentration into higher density residential areas, but on the specific patterns which this trend assumes. It is anticipated that, in general, households will tend to live closer to work at higher densities and will be more concentrated around the urban core and major sub-centers within the urban area.

Finally, the effect of energy prices on transportation demand will be effected also by its impact on the prices of all other goods, i.e., real income. In particular, there is the question of the extent to which adjustments will be made between transportation and other energy-intensive forms of consumption. Furthermore, insofar as an urban area's income is generated by the production of energy intensive goods, the question arises as to the net impact on the terms-of-trade between that urban area and the rest of the world, and whether the urban area's trade balance will be improved or will deteriorate. In an open economy such as that of an individual urban area it must be assumed that prices of goods are determined externally. Trade effects will therefore depend on the price elasticities of imports and exports, in other words, the extent to which the urban area is able to conserve on higher cost (because of energy prices) of imported goods versus the opposite adjustment by the rest of the world to the production and export of goods of the urban area.

2. Model Features

Prices are used throughout the model and act in setting resource allocations and clearing markets. Thus the impact of the change in the relative price of a particular commodity or service such as energy can be demonstrated directly in the various subsectors of the model. In the allocation of consumer and public sector budgets, the extent of

substitution among types of goods and services is made possible by their common attribute characteristics. An important sector of the urban economy with respect to a good such as energy, which has such a pervasive impact, is the urban area's trade with the rest of the world. Trade relations are also given explicit treatment in the model (Module 11).

3. Simulation with the Model

One type of simulation which might be performed in this area would consist of a sequence of simulations corresponding with a similar sequence over time of transportation policy actions. This type of simulation illustrates the capability of the model to trace out a path of adjustment to a changing level of exogenous or policy input. As has been pointed out earlier, however, this adjustment path is not a forecast; rather, it shows the ultimate adjustment which the urban area economy would make to the specific incremental change by the time all markets including those for investment obtained a stable equilibrium.

Initially it might be assumed that consumers have fixed travel habits with respect to the price of fuel. This represents a very short-run situation. It would be possible to calculate (externally from available studies) the impact on travel cost. In addition, the prices of other categories of goods used by consumers and producers could be evaluated, using "energy budget" types of calculations. With the ad-

justed set of prices, i.e., prices of fuel and other energy using goods, the allocation of the consumer budget could be made between mass transportation and the use of the automobile. In addition, shifts in the whole range of consumer goods would be shown. Among these, importantly, is the choice of housing and the influence of the housing market in determining the spatial pattern of residence. These might be expected to be altered as a reflection of changes in the cost of production and operation of housing, tending to shift demand toward higher density forms. On the production side the effect of energy prices on the urban areas terms of trade with the rest of the world would result in changes in the urban area's income and employment levels and consequently on the distribution of consumer expenditures among public and private goods.

In a second round, there might be introduced some reduction in costs of travel to reflect changes in automobile characteristics to achieve greater fuel economy, improved transportation management and higher loading of vehicles. Alternative versions of the second round of the scenario would include a continuation of the energy prices assumed for the first round, or further increases in the price of energy. The resulting simulation would show the extent to which adjustments could be made to compensate for the increased price of energy without large scale investment in transportation

facilities.

In a third round, changes to the transportation system -- specifically, the road network -- would be introduced. This could be accomplished, for example, by limiting the area devoted to roads within each geographic sector.

These changes in the physical capacity of the road transportation system, by altering levels of congestion would affect the cost of travel and consequently the residential distribution of households among sectors. The feedback effects of costs of transportation due to congestion, the specific costs of fuel and the household location decision will demonstrate the impact of changes in the transportation system in either mitigating or exacerbating fuel costs and consumption.

This type of result indicates another potential motive application of the model. Both growth patterns and non-transportation policy changes alter the pattern of demand on the transportation system. It is possible, through simulation with the model, to estimate the pattern and extent of transportation -- oriented changes necessary to either compensate for these exogenous effects, or to enhance them in some particular direction. In this instance, it would be possible, having made some decision as to the best trade-off point for enhanced mobility versus the discouragement of travel and consequent saving of fuel, to choose that transportation solution from among some discrete set which most nearly ac-

complishes the desired outcome. Calculations of costs corresponding with the various transportation configurations would have to be made, as the model now stands, externally; but further extensions of the transportation module would allow the incorporation of such data (see Section 3.6).

An additional question which might be examined in connection with this and other scenarios relates to the trade-off between the high capacity, capital-intensive fixed rail mass transportation system and road oriented mass and private transportation systems. The general approach would involve identifying opportunity costs associated with either excess capacity or congestion. The implementation of the approach would involve running a number of simulations. First, a forecast would be made of the future price of fuel. This would be converted, in the model, directly into transportation costs and indirectly (by way of the housing market) into residential location and travel demand. A variety of transportation systems could be examined and the one most nearly optimal (considering all economic consequences) could be chosen. In the second set of simulations, the transportation network would be held constant while the price of fuel would be altered both upward and downward from the original forecast level. If the simulators were willing to place probabilities on the various price levels, a type of estimate of the risk associated with optimizing on the specified

forecast level of fuel price could be obtained.

3.5.4 Scenario 3 -- Technological Change: The Information Revolution

1. General

Changes are taking place in the technology of production and consumption which may have a profound effect on urban form in transportation patterns. The impact may be as significant as that of the automobile. We refer to that set of innovations in information and telecommunications technology which has come to be called "the information revolution". While this change may take place gradually, over the short term, we can expect an acceleration of change in systems of telecommunication, information processing and control, instituted not only for the productive sector but also for households. According to some observers the strong growth of the service sector, associated with secondary labor force participation in the household, especially of women, will be reversed as a result of technological deplacement by increasingly sophisticated electronic hardware. A large proportion of those employed may work in environments quite different from those of the present. With greatly expanded telecommunication and teleprocessing capabilities working at dispersed work stations or at home may be common and even the dominant mode of work. Such a development would, clearly, have important implications for urban form and transportation. It

has been estimated that 84% of urban vehicle-miles are accounted for by trips which have the purpose of exchanging ideas or information and which are susceptible to substitution by telecommunications. Studies have shown, further, that 16% or urban vehicle-miles could be currently substituted for by telecommunications, even with current telephone technology and better trip planning.* This proportion could be greatly increased as information technology evolves and as firms and households become accustomed to its use for a variety of functions.

2. Model Features

The use of the model as a conversion between observable goods and services, on the one hand, and attributes, on the other, to derive household and local public body utility levels makes it well adapted to the inclusion of the impacts of technological change of various types. The model allows the expansion of the set of goods available to industry, consumers and the local public body and the substitution between new and old goods, including transportation.

The creation of new products and changes in the production costs of traditional products (due to more efficient production processes) leads to changed patterns of demand for the urban area's products. This change pattern will depend upon the extent to which the urban area participates

*See article by Polishuk in the List of General References (Appendix G).

and/or is able to enter industries which partake of the technological change. It is possible, therefore, to compare urban areas having a substantial "high technology" industrial component -- including information-oriented activities -- with those oriented to more traditional products.

Technological change is accompanied by shifts of workers among industries and changes in the overall pattern of skill requirements. The model not only accounts for labor requirements for specific industries in the urban area but also makes it possible to alter skill levels by appropriate allocation to education and training.

3. Simulation with the Model

In the goods/attributes matrix it would be possible to introduce information products and services as an explicit category. Alternatively, it would be possible to change the attribute loading of individual goods to reflect their greater efficiency in the provision of particular attributes. In the case of information-related goods, the most closely associated attributes might be leisure, accessibility and possibly environment. Some or all of these attributes would also be associated with transportation services which might in addition display further attributes such as comfort.

Assume that the price of information relative to transportation services were to decline and consequently that the consumer could obtain more in the way of leisure, accessi-

bility and environment at the same income level without sacrificing the enjoyment of other attributes. The model would show,via consumer demand calculations, how household budgets would be reallocated between public and private goods and among private goods. It might be expected, if information and transportation services are associated with much the same attributes that demand for the latter would decrease; however, this is not necessarily the case. Transportation or any other commodity or service might be complementary with information services in consumer demand and would therefore actually increase both in absolute level and in share with the consumer budget. It could also be demonstrated, by using reasoning about how the attributes associated with transportation and other non-information services might change in response to the information revolution by the imposition of judgmental values, how these various goods and services change in their complementarity and substitutability. Transportation, for instance, might become much more specialized to goods transport and to person transport with very high comfort levels.

Another influence on the demand for transportation, in this case on the differential demand for modes of transportation would result from the labor displacement effects which the model would show via a decrease in labor requirements per unit of output in specific industries. Dispersion

of residential activity would be expected to take place as the result of replacement of space-related accessibility (transportation systems) by non-spatially related accessibility (information technology). This would be accomplished in the model by generating decreased costs of (i.e., expenditures upon) transportation which would have the effect of increasing differentially housing bid levels by households at the periphery as compared with the central area.

Another effect would be via labor demand in terms of the changes in labor force characteristics of employment in information versus that in the production of transportation and other goods and services. There could be unemployment stemming both from net productivity increase and from a mismatch in the configuration of labor force requirements between increasing and declining sectors. It would be possible to show, however, how retraining and education, at current levels, or under some positive alternative scheme, might or might not eventually overcome these problems.

Interindustry linkages would provide another channel for tracing through effects. Specifically, the change in relative demand for non-labor inputs would result from changes in the configuration of production, which in turn would be due to change in local demands for output.

Finally, effects would be traced by trade between the urban area and the rest of the world. Those information-oriented industries in the urban area would produce at lower

prices. By using alternative assumptions as to the extent to which the rest of the world also benefits in terms of the price that it is now willing to pay for the urban area's output, the model can be made to yield alternative levels of production and income for the urban area. One might want to assume, for instance, that a particular urban area has a "comparative advantage" in the production of specific goods related to the information revolution (e.g., "Silicon Valley" in California). Increased demand for such goods would show up to some extent in demand by the local population for the output of local industries. A far more important effect, quantitatively, might be from the rest of the world which, over some period of time, would be unable effectively to substitute for these products, i.e., the urban area would be in a monopolistic position. Effects of this sector upon employment and income in the area could then be observed.

This last observation leads to another consideration with respect to the use of the model for simulation. In the simplest case, the urban area in the model is viewed as an individual physical area and its behavior with respect to the rest of the world is that of an "open economy". Prices in trade with the rest of the world are uneffected by the actual volume of trade in either direction. If, on the other hand, the synthetic urban area examined in the model simulations is viewed as representing all urban areas taken as a

whole, then such an assumption becomes unrealistic. If a development such as the information revolution is common to all urban areas (even though it may have particular effects on individual urban areas such as the one cited), the changes in the configuration of production and consumption predicted by the model may be taken as representative of the nation's urban areas as a whole and consequently, to a large extent, for the nation as a whole.

Similarly, it would be possible to examine within a set of simulations a group of urban areas having trade relationships. This would allow explicit examination of the "system of cities" which characterizes much of the nation's economy. It would be necessary to quantify the reaction coefficients on demand and supply of traded goods -- quantities which could be well approximated from econometric studies oriented in part to a spatial market. It would then be possible to examine directly differential effects on exogenous changes among different types of urban areas as well as the complementary and competitive aspects of differently composed urban areas and the contribution of specific programs in bringing about synergistic growth, on the one hand, versus destructive competition on the other.

If the model is simulated in this way (to represent the aggregate or urban areas), it also becomes possible to examine the effects of a wide range of macro economic poli-

cies on the urban portion of the economy. These include questions such as monetary policy and the ability of local areas to borrow for capital construction, fiscal measures, i.e., income and other taxes and alternative bundles of programs such as the choice between revenue sharing, CETA and other "soft" programs versus programs of public works, highway construction and defense and space programs. In addition, the effects of non-policy macro changes, specifically inflation and recession can be traced.

3.5.5 Scenario 4 -- Growth Patterns: Urban Sprawl

1. General

It is asserted that urban growth and concentration leads to the generation of spatial externalities which in combination with a fixed capital stock cause extension at the fringe of the urban area in a pattern of low density "sprawl". This type of development is alleged to inflict costs upon some activities in the core, including central city government, firms and households, especially those with low incomes. This pattern of development makes it possible for households who can afford to do so and for some types of industry to locate in the fringe on low cost land. At the same time, households of lower income and industries which cannot produce efficiently without close proximity to complementary industries and labor supplies are forced to remain

in the core where, because of continued growth and numbers of the overall urban area and the development of a transportation system favoring radial access, they face increasing costs of congestion.

As a general approach to this problem, it might be proposed to try and influence the distribution of activities in the urban area more or less directly. (An alternative might be to try and preserve the "sprawl" type of growth while compensating those who tend to become worse off as a result).

From this general approach some specific alternative approaches might be generated. As an illustration, it might be decided to try and exert influence on the level and distribution of land values as determinants of activity location. (An alternative might be reorganization of urban land use control, e.g., at a metropolitan or state level.)

From this specific policy approach several alternative programs might be considered. One example would be the construction and maintenance of a much denser and higher capacity transportation system in the core area, with limited access in fringe areas. Alternatives might include public purchase of land in urban cores which could be leased at prices such as to depress levels of land values in the core generally or public purchase and "slow release" of land at the periphery. Another approach, recently taken as policy in Massachusetts, is to concentrate public investments in older urban core areas, including public transportation, to induce or attract (or maintain) private downtown investments.

2. Model Features

Taking the first example of the transportation program alternative we can see how the model might be used to examine the systematic effects which a program would entail. Some important first-order effects would be as follows:

a. network loading and congestion;

b. changes in the relative price of commuting to different locations and by different modes;

c. competition by activities for accessible sites;

d. bidding up of land prices in some locations, relative depression in others;

e. changes in densities and replacement of land-extensive by land-intensive uses, e.g., residences replaced by offices;

f. adaptation of land-use controls to reflect the competition for sites.

3. Simulation with the Model

In order to be able to simulate these effects, a model such as this, representing the behavior of a number of sectors is necessary. Without some such model, the spatial distribution of effects would be impossible to gauge. In the process of adaptation of the urban system to the specific policy, events would be likely to occur which could lead to a much different outcome from the one which, in broad outline, could be predicted from deductive reasoning. These dynamic effects require an understanding of the multitude of adaptational mechanisms involved in the urban system which channel and redirect market forces. These would include:

a. the rate at which changing land prices affect expectations of future prices;

b. behavior of land owners in assembling land and holding it in low-yield uses for expected future gains;

c. technological adaptation of the means of transportation and the influence of the distribution of costs upon various segments of the population in rendering such technological change acceptable;

d. possibility for production methods of local industry to be changed in adapting to changes in transport costs;

e. the competitiveness of the city's exports governing whether increased costs would lead to industry flight from the area or lowered costs would lead to the birth of new industry;

f. the adaptation of housing production and the creation of neighborhood effects, physical and political, tending to dampen the productivity of the transportation system;

g. changes in secondary labor force participation altering household income expectations, consumption patterns, the configuration of local output and the balance of trade;

h. the reaction of the public sector in retaining the policy and instituting complementary land use controls as the distribution of costs and benefits becomes apparent.

These and other <u>secondary effects</u> might influence the outcome of such a contemplated policy. By simulating them according to plausible behavioral rules, it may be possible to demonstrate that their feedback could indeed be significant and that their investigation is worthy of analytic and empirical investigation. Such investigation would

provide specific sub-systems and quantitative parameters for introduction into a more advanced version of the model.

3.5.6 Applications of the Model: Summary

The scenarios described above have illustrated a number of types of applications of the model. These can be summarized as follows:

First, the model can be employed at one of several levels. Internalized -- the simplest form, in which levels of exogenous parameters and constraints are altered according to some policy under consideration, e.g., as in changes in sectoral funding formulas. Comparative Structural -- levels of exogenous variables such as the configuration of the transportation system, pattern of industrial location and demographic characteristics are altered from scenario to scenario, demonstrating the long run effects of such individual changes on urban areas of different characteristics. Quasi Dynamic -- involves rerunning the model against trends in exogenous variables reflecting some set of forecasts, the output of endogenous variable levels for each simulation being inputs to the next -- to represent the direction of change in economic actvities and distribution induced by various growth scenarios.

Second, in terms of policy and program design the model may be used in one of two principal ways:

1. Direct -- in which the impact of a program

introduction or alteration can be traced through the simulation's outcome in terms of changes of endogenous variables.

2. Compensating Adjustment -- in which there is calculated the extent to which transportation changes need to be made either to compensate for changes in non-transportation policies or non-policy exogenous variable in order to preserve the prior level of income and/or other output criteria; or to enhance the effects of other developments, i.e., to maximize the levels of such criteria and variables.

3.6 The Treatment of Transportation and Extensions of the First Version

In the initial version of the model, the transportation problem is treated simply. This simplified treatment preserves the most important economic features of transportation as an object of demand and an input to production and the maximization of consumer utility. At the same time considerable savings are obtained in computational requirements as compared with the more conventional (multi-modal) approach. This simplification could be dropped from subsequent versions. Within the project being proposed, there would be an investigation of extentions to the treatment of transportation. The feasibility of their introduction would depend upon progress in overall model development.

The following assumptions are made:

- Transportation costs are associated only with the residence-to-work trip of the head of household.

- The route chosen for the residence-to-work trip is the one which minimizes distances.
- There is only a single mode of transportation but there exists a continuous scale of mode quality, which incorporates both comfort and speed.
- The price of mode quality varies by its level; specifically the curve of price against mode quality is strictly concave downward.
- It is assumed that the traveler on the transportation system chooses a level of mode quality such that the ratio of marginal utilities of mode quality to the composite good equals the inverse of their price ratios.
- The schedule of mode price versus quality level is a function of the utilization level of the branch or branches of the transportation system being used.
- As a consequence of the above the expenditures on transportation can be taken to depend upon the income of the individual worker and the utilization level of the route between residence and work place.
- Differences in estimated transportation costs, based upon previous period work places, are incorporated into the household's housing bid; hence, transportation costs will influence residence location.

In the initial version of the model, the transportation network is not an object of public expenditure. Costs, including those of congestion, are borne by users of the system, where cost to the individual is calculated as the average cost to all users of a specific route, adjusted for individual income and price elasticities of mode choice.

Some of the questions which could be investigated

with this initial version are as follows:

- What are the effects of different transportation system patterns, e.g., radial, on land value distribution, level of income, etc.?

- How do congestion costs and changes in the transportation system affect the price structure of housing?

- What are the effects of charging tolls (according to level of congestion on the branch, according to income, according to length of journey, according to destination, etc.) on the distribution of residences and value of residences, on the levels of employment in various industries, on the level and distribution of income, etc.?

- What are the effects of various policies for expanding the transportation system upon the distribution of housing and production activities, level of income, etc.? We might start initially with a uniform transportation capacity in each sector, adding capacity, e.g., in a sequence determined by level of congestion and land price in each preceding period.

Possible alternatives and extensions which will be investigated in the course of the project include the following:

- Discrete modes could be introduced which could be expressed in terms of attributes and prices including time "prices," given the utilization levels, and which could then be entered in the consumer budget allocation as a second-round optimization, the initial choice of level of housing expenditure being given. The choice of mode could then be derived directly from the optimal allocation of money and time budgets.

- The population could be allowed to choose an optimal route between residence and work place on the basis of attributes relating to speed, comfort, and out-of-pocket expense where different sets of modes are available on different routes.

- The population might choose a single route as part of the optimization based on past prices, then subsequently accept a specific mode on the basis of that level of expenditures, e.g., by dividing up the modes according to the cumulative distribution of expenditure levels.

- Allowing discrete modes with prices specific to node pairs would introduce a range of mode price and choice problems:

  - what subsidy to mode(s) would cause the least congestion per passenger?

  - what are the income distribution effects of such subsidies?

  - if fixed capital is introduced into the model, what would be the utilization of the facilities and what would be the appropriate timing of replacement of the facilities under various conditions?

- The transportation system could be made an explicit item of public expenditure (private vehicles can be included even in the initial version of the consumer budget) rounding out the supply side and thereby creating a market for transportation.

3.7 Study Output and Conformance with TSC Objectives

The project would be directed to the first phase of model development beyond the existing design. This initial phase would consist of the development of the modeling system in the form of computer software and the design and running of a series of trial simulations, displaying the stability of the model, with adjustments to be made, if necessary, to achieve required stability properties.

Within the scope of the project, there would be included an initial reformulation, at least in design terms,

of the model to include a more detailed transportation sector.

Toward the conclusion of the project there would be a review by experts in urban economics, transportation and modeling, to obtain some external judgment as to the plausibility of relationships incorporated in the model as well as the importance of relationships not represented, as a guide for further development.

The overall project meets two objectives set out in the original RFP very well. These are:

- The formulation and application of policy dealing with the future patterns of cities and development.

- The interaction of economics, energy, land use, housing, water and sewer facilities, for example, should be examined as they relate to national urban policy but with particular reference to transportation.

The proposed model is in no way a strictly academic approach. While being firmly rooted in economic theory, it is responsive to explicit policy analysis concerns of practical decision makers. The model can be calibrated with data readily available for published sources and data files commonly maintained by federal and stage agencies and by area-wide transportation study groups. It is capable of being geographically disaggregated to areas small enough to be useful to local planners, analysts and decision makers (e.g., census tracts or neighborhoods). It is essentially a spatial allocation model of urban development.

4.0 MAJOR TASKS

The following comprise the major tasks associated with the development and trial simulation of the initial version of the model. Estimates of corresponding personnel requirements are shown in Section 6.0

1. Procedures will be set up for project management. These procedures will deal with internal coordination and management of the various tasks and activities comprising the project, from the design and implementation of filing and retrieval systems for non-machine-readable data and other information, to reporting procedures and liaison with the client.

2. The algorithms constituting the computational version of the model will be designed and written. The initial design is presented in Section 3.4 and Appendices A-D. This step will include further scrutiny of the logic of the initial design and decisions on structuring of the blocks of modules, depending upon the degree to which individual relationships can be incorporated into the optimization scheme. Further modifications might also result from tests of linkages among modules when the design is implemented in Step 6.

3. A data directory system would be designed and data for quantifying variables and parameters would be compiled. An initial survey of sources of data for model variables and parameters, respectively, is contained in Appendices E and F.

4. A system for inputting, outputting and internally

manipulating information for the model would be designed. The design would deal with such elements as data linkages, coding structure, report generation, databank design and retrieval procedures, etc.

5. A set of simulation experiments would be designed for ultimate use within the project with the initial version of the model. These experiments might include one or more of the scenarios presented in the present report and/or others which might be suggested by the client.

6. The model programs would be developed. This would consist of the coding and implementation of the programs for optimization, simulation, other specific calculations included in individual modules, and sensitivity analysis.

7. The model programs and data manipulation programs and procedures would be tested.

8. An experiment would be made with trial data. While the collection of data for the composite urban area is proceeding, initial values obtained as well as judgmental values for those not yet obtained at that point in time would be entered in a matrix and used for a set of experiments with a coded model in order to gauge the stability, economic consistency and reliability which might be expected subsequently.

9. Technical tests of the system as a whole will be conducted.

10. Documentation will be prepared of programs, systems

procedures and data files.

11. The databank will be established with the creation of the files for the composite city and for the parameter values and with the testing of retrieval, error-testing and other routines.

12. Sensitivity models will be developed. A variety of sensitivity procedures and parameters would be developed with respect to variations in the principle policy variables contained in the model.

13. The preliminary design for a revised transportation algorithm will be conducted. The nature of such possible revisions has been discussed in Section 3.6. The design would entail the identification of additional outputs available, additional input requirements and sources, changes in system requirements and the resources required for implementation. It is possible that, if requirements are not too extensive, the actual implementation of revisions to the transportation and associated other modules could be incorporated within the framework of the project.

14. A decision model would be developed for the selection of policy settings. In order for the model to have a maximum usefulness to the client, it will be necessary to define and identify the types of controls or other policy instruments which the user wishes to examine, the types of growth situations of relevance and the form of output desired. The

impact evaluation model would then be developed and tested with the chosen scenarios.

15. The model system would be evaluated in conjunction with the users. This step would involve a series of experiments with the model which might be variations of the basic scenarios, a review and discussion of possible further applications of the outputs and the assembly of reactions, experiences, etc., on the part of the client.

16. A prioritized schedule for research and further development of the model would be developed. Inevitably, in the course of model development a number of lines of original investigation would be identified which could potentially provide important refinements to the formulation of the model or increase the accuracy in estimates of quantitative magnitudes. These thoughts would be developed and formalized in a set of recommendations for such research. In addition, as the result of having finite time and resources for the project, some potentially useful developments would be identified which could not actually be pursued within the framework of the project. The project team would be assisted in the formulation of these observations and recommendations by a panel of experts in urban economics, urban policy and simulation model building. This panel would be convened toward the end of the project and its input would serve as part of the evaluation of the model with the clients.

17. The model system would be introduced for use by the client. The end product of the model development included in this project is intended to be a system which could be employed by UMTA or others both on a recurrent basis to examine developments in the economy affecting urban areas and for special policy studies. To develop a bridge between model development and its use for simulation in an institutional environment, there would be a period of training and education of the users in order to acquaint them, not only with the mechanics of model operation but also with the potential as well as the limitations of its use.

18. A Final Report will be prepared.

19. Quarterly Progress Reports will also be prepared

Sections 5 through 9 have been deleted.

APPENDIX A:

EQUATION STRUCTURE, ASSUMPTIONS, AND ANALYSIS WITH THE MODEL

The discussion in the body of this report summarized a number of questions of importance in urban economic analysis oriented toward transportation policy analysis. In this appendix, we shall present a description of each of the major components of the model, to demonstrate how the model may be applied in such analysis. Each section will include a listing of major assumptions underlying the model, a mathematical formulation of the model and a discussion of the ways in which the model might be employed to examine a number of questions suggested in the body of the report. This latter discussion is meant to be illustrative, pointing only to some of the more obvious issues which might be investigated. It is divided into two parts. First, applications are listed which might be made with the model as implemented in the computational system to be outlined in Appendix B. In some cases, minor modifications would be involved to the default version represented by the specification, e.g., altering some parameters manually over several "periods" of operation rather than allowing them to remain constant. In others, variations could be accomplished by constructing alternative data structures so as to reflect the underlying distributions of variables and the parameters of relevance for the particular question under investigation. Second, possible alternatives to and extensions of the model are suggested which would allow the examination of questions which cannot be adequately addressed with the present version. Such extensions would involve major revision of modules as presently designed, incorporation of additions modules, or alterations of the sequence of operation of modules.

The model as a whole and each of seven major sectors are presented: the public sector, production, consumption, housing, wages and prices, transportation and land.

Reference to modules in the discussion of each

sector pertains to the computational modules to be specified in Appendix C.

A.1 The model as a whole

A.1.1 Assumptions

(a) There exists within the urban area a population of fixed size, tastes and labor characteristics.

(b) Production and distribution are undertaken by firms fixed in numbers, technology and location of plants or distribution facilities.

(c) Labor and commodities may be exported and imported at fixed wage rates and prices.

(d) While land and the domestic labor force are fixed, capital in the conventional sense does not exist, i.e., commodities of all kinds are produced and consumed in each period.

(e) There exists a single public body which provides public services in the urban area according to an aggregate welfare function, subject to the allocation of consumer budgets and additional revenues and constraints imposed by higher levels of government.

A.1.2 Comments and questions to be investigated

(a) The model does not allow for growth in population or number of firms explicitly. It is desirable to abstract from growth factors, however, in order to examine, e.g., the welfare effects of various public sector actions, a direct matching being possible between individuals in the population before and after such actions.

(b) Growth in income is possible, depending upon concentration of production in more efficient firms, changes in world prices, complementarity of inputs and outputs of domestic firms, efficiency of the transport system, etc. With fixed parameters, such "growth" represents convergence toward a steady-state situation but allows us to examine whether the steady-state

is unique, within bounds, and how different initial configurations of variables and parameters affect the speed of convergence. Alteration of parameters could produce a true growth economy in a limited sense. One of the most important types of question to be investigated with the model would be the effects of various sets of parameters and initial levels of variables upon the stability, rate of growth and distribution of income.

(c) Since commodities are not durable, the solution of the model in each period represents a special kind of equilibrium, one in which the past history of prices is reflected only in expectations of price in the current period but not of prices in the future. Where expectations and realizations do not match, agents in the various markets attempt to correct their behaviour once-and-for-all in each period. In this sense, individuals are able to adjust in each period to long-run levels. For the system as a whole, however, long-run equilibrium is not achieved by such behaviour. This could be demonstrated in running the model, by holding all parameters constant over successive periods. The system would generally require more than one period to converge to an equilibrium, defined, e.g., as some band of variance of the values of the model variables. The investigation of relationships between individual adjustments and the adjustment of the system and of the growth paths generated, without the complications of multi-period production and consumption is another problem area of major interest.

(d) Export and import prices may be expected to play an important role in determining the distribution of activity levels in the system in its steady state, as is appropriate in the open urban economy.

Changes in these prices, acting through a series of implicit "multipliers" will alter activity levels in different sectors and industries differentially during its adjustment to these changed prices. A one-period proportional change in all export and import prices, e.g., would, as in the conventional international trade analysis, alter all prices in the new steady-state, achieved after some periods of adjustment, so that the initial distribution of activity levels is restored. The time paths of adjustments in production, wages and domestic prices would represent a way of investigating impacts on the various sectors of such changes. Differential changes in export and import prices could, on the other hand, lead to permanent growth or contraction in real income. In the present model, one internal source of such growth would stem from economies of scale in exporting vs. importing industries. The other source is more peculiarly "urban" in nature. In the present model, firm locations and public service areas are fixed. Differential growth in production among various industries would lead to different residential patterns consequently different sets of prices for transportation and public services. The efficiency of the urban area as a productive unit would be altered.

3.1.3 Possible alternatives and extensions

(a) If firms were allowed to relocate each period, and if, in addition, public service delivery area boundaries could be re-drawn each period, these urban effects in the response of the system could be eliminated, and such response could be compared with the partial effects of these and other elements of fixity and spatial

interdependence. In addition, steady-state configurations of firms and political boundaries could be examined under various configurations of parameters.

(b) Growth in population and numbers of firms could be introduced. The effects of such growth relative to the model with fixed numbers, could be compared for the two types of steady state-static and dynamic. In particular, what are the costs of increasing congestion.

(c) In addition to growth in population, demand for exports and supply of imports might have elasticities between 0 and 1. It would then be possible to ascertain an optimal city size. With growth in demand and supply by the rest of the world, an optimal growth rate for the city could be ascertained.

(d) The public sector in the present model has both allocative and re-distributive functions. To these might be added a stabilization function. Initially, this could be accomplished by fiscal policy and direct controls, the two types of mechanisms open to it in the present version of the model. Conventionally, the stabilization function is thought of as residing with higher levels of government. The local public body, however, may, e.g., be able to "zone out" more instable industries. A comparison of the effects of such measures with, e.g., stabilization of export and import prices through tariffs or transport subsidies would be of interest.

(e) If fixed capital were introduced, it would be possible to investigate the important question of the effect of the location of specific facilities and households upon location decisions over subsequent periods. For a given set of parameters of the system and even with firms and households fixed in numbers, it would

be anticipated that different sequences of decisions affecting location would lead to different steady state outcomes. In addition, expectations about future returns to presently-existing stocks would enter into the determination of prices and levels of maintenance of the stock. Finally, questions pertaining to circulating capital and its distribution and its relation to investment in the fixed stock, i.e., problems of finance, could be studied with the incorporation of a financial sector.

A.2 Public sector

A.2.1 Social utility function - module no. 1

A.2.1.1 Assumptions

(a) The utility of individuals (where each household is treated as an individual) in the urban area is derived from attributes which are associated with both market and non-makret commodities; these attributes are linear and additive in the utility function.

(b) Each good may be associated with the levels of some subset of attributes but a set of attributes A_1 associated with market commodities and the set of attributes A_2 associated with non-market commodities are disjoint.

(c) Within each district of the urban area herein referred to as "sector" individuals aggregate their utility functions.

(d) The level of each attribute type associated with a bundle of commodities is modified by past levels of the attributes, to account for expectations, satisficing and other forms of dynamic behaviour. This modification is specific to each district of the metropolitan

area (herein referred to as "sector"). Individuals are therefore assumed to form expectations, etc., not necessarily according to their own individual experiences, but according to the experience of their sector of residence. In the simplest case, past levels of attributes achieved do not act to modify the commodity - attribute matrix.

(e) A representative to the local public body is elected whose utility function is identical with the aggregated utility function of the individual constituents within his sector, except that the modification for past attribute levels may differ.

(f) All services provided by the local public body are market commodities, i.e., they involve a specific monetized cost; but 1) individuals must purchase public services as a composite, rather than separately; 2) legal constraints imposed by the local public body are not market commodities.

(g) The utility function of the local public body (LPB) is obtained by aggregating the utility functions of the individual sector representatives weighted by some transformation of the population of the individual sectors.

(h) Zoning for the current period as based upon the utility functions of the population is aggregated according to their distribution in the previous period.

(i) The utility function for the local public body includes the percentages of each sector which are zoned in the various uses as well as the proportions of the individual zoning types for the urban area as a whole.

(j) Changes in the distribution of zoning are constrained by the distribution in the previous period, i.e., it may change only within limits.

A.2.1.2 Model

$$V_i = (A_{11} + A_{12} + \dots A_{1m} + A_{21} + A_{22} + A_{2k})^{T_6}.$$

$$U_j = \sum_{i\varepsilon j} (\sum_q A_{ig} + \sum_r A_{ir})^{Tj} \quad q=1,\dots m \quad r=1,\dots,k$$

$$U_p = P_j \sum_j U_j$$

where

V_i, U_j, U_p = utilities of individuals, representatives and for the local public body, respectively,

A_q, A_r = attributes associated with market and with non-market commodities, respectively

T_i, T_j = lagged attribute levels of individuals and of representatives respectively

P_j = weighted population of each sector

A.2.1.3 Comments and questions to be examined

(a) The model embodies a conventional or pure model of government i.e., one which is passive merely adding individual utilities, except that the public sector may "misjudge" dynamic effects by adapting too quickly or too slowly.

(b) How do different patterns of residence affect representation in government depending upon:

i) differing sets of weights on attributes

ii) differing population distributions of characteristics

iii) different delineations of electoral boundaries (sectors do not necessarily have equal numbers of constituents).

(c) What is the payoff to households of varying characteristics from joining "clubs" or enclaves. This could be investigated by imposing varying degrees of homogeity on sectors or by varying the weighting given to the population of each sector.

A.2.1.4 Possible alternatives and extensions

(a) The LPB representative might weight the utilities of his constituents differently depending upon the existence of various "community" groups, i.e., neighbourhood associations and other interest groups.

(b) The influence of firms on the LPB representatives and utility functions could be introduced, e.g., as a function of numbers employed or net worth, etc.

(c) The local public body representative's utility function may be oriented toward purely personal ends, e.g., maximizing the probability of re-election which might in turn involve a weighting of the utility functions of voting constituents, firms (contributors) and other representatives of the LPB representing cooperation in the allocation of public revenues and/or collusion to obtain greater power over the long run.

(d) Somewhat more dynamic versions of the above, e.g., assuming depreciation of the LPB representative's stock of good will with his constituents over time, concentration of popular actions shortly prior to election, with relatively greater emphasis on actions designed to promote long term power in other years.

(e) The parameters of the utility function might be allowed to vary according to occupation type, age of head of household and skill level. Allowing for this variation in "tastes" would have three purposes:

   i) as a way of introducing non-economic considerations, e.g., individuals may become less tolerant of law violations with age and it might be desired to reason about variations in the parameters from a sociological or socio-psychological model;

ii) as a way of expressing certain economic variables, e.g., level of permanent income, which are not presently explicitly carried in the model from period to period but which might in certain models be expected to affect the marginal utility of income. Thus with increased age of household head it might be asserted that the utility of police protection (criminal justice) increases at each level if the marginal expected property loss in money terms increases at a faster rate than expected marginal tax payments for criminal justice.

iii) the variation in parameters with household characteristics is also a way of storing information, e.g., if households move from place to place, the low levels of public service of their past residence may influence their aspirations and expectations, e.g., with regard to a level of public services such as criminal justice. At present it is impossible to store information according to past residence for more than possibly one period but it would be relatively easy to embody in these parameters some average history of households in each age, etc., class.

A.2.2 Regulatory constraints - modules no. 1, 2

A.2.2.1 Assumptions

(a) In general the correspondence between regulatory constraints and their effects in terms of attributes corresponds with a satisficing behavior on the part of individuals. Accordingly, utility is made a function of levels of constraints themselves i.e., of inputs and of

the level of output which obtains under the existing level of constraint. For zoning constraints, e.g., the contribution of such constraints to attributes depends upon the existing distribution of land use.

(b) Actual and expected levels of externalities determine the level of tolerance for zoning constraints. The utility for zoning is derived from the actual land use mix within the urban area and within the household's own sector.

(c) The household views land use in its own sector differently from land use generally. Whether a household derives additional utility from additional lands being zoned for a particular use therefore depends upon whether there is "satiation" with respect to that type of use in its own sector. If there is such "satiation" then the household would tend to want to have land zoned for that use elsewhere than in its own sector subject to its notions of the proper balance of land uses for the urban area as a whole which would contribute to some general level of welfare which also affects its own, e.g., the level of urban income.

(d) The optimal land use distribution for each individual therefore depends both upon the overall distribution within the urban area and the distribution within his own sector. The former is associated with a balance of land uses while the latter affects the immediate environment, e.g., more industry leads to more employment generally and higher incomes as well as a bigger tax base, etc.; but more than some specific proportion in the household's own neighborhood leads to decreasing utility.

A.2.2.2 Model

$$V_i = C \cdot L^{k_{1i}} {}^{-k_{2i}}$$

where

V_i = utility of individual i for a specific type of constraint

C = level of the constraint

L = level of "output"

k_{1i}, k_{2i} = constants specific to the individual

A.2.2.3 Comments and questions to be examined

(a) Zoning and other legal constraints are not part of the budget regime and therefore even in equilibrium their resource costs are not directly measurable. It would be possible with this model, however, to examine the effects, in terms of aggregate urban income, as well as the distribution of income, of variations in the parameters of the zoning and pollution utility functions, of changes in method of aggregation of these utility functions and of changes in constraints which govern the degree to which the proportions of zoning types in a sector may be changed from one period to the next. Such calculation can be made more directly if the decomposition approach outlined in Appendix B proves to be feasible.

(b) While these latter constraints, i.e., on the amount of change in zoning from period to period, are introduced primarily as a device for stabilization they also have the effect of altering the final outcome. This effect can be seen most clearly by noticing that the zoning utility function itself depends upon the distribution of zoning as between the individual's own sector and the rest of the urban area.

(c) The utility for pollution constraints depends upon the actual level of pollution experienced in the household's own sector. The physical characteristics of pollution leading to over-spill would, however, necessarily spread the actual level in a more or less continuous way over adjacent sectors. This suggests a variety of possibilities for households in sections of the urban area encompassing several sectors to form coalitions for the purpose of reducing pollution caused by firms or households in other sections or of imposing penalties upon them via their representatives.

A.2.2.4 Possible alternatives and extensions

(a) The local public body might attempt to maximize its property tax revenue or some weighted combination of property tax revenue and social utility. Within the constraint of some maximum allowable tax rate, it would achieve this objective by zoning and the location of public services so as to yield a maximum aggregate property value. Ideally, the LPB would attempt to account for property owners' pricing procedures in the short run and optimal conditions of production and distribution in the long run. A more heuristic procedure for the local public body, assuming property tax revenues to be part of the objective function, and one more in accord with empirical observation would be to give preferential treatment to those sectors in which property value per area of land is highest or increasing most rapidly. "Preferential treatment" in this instance means relatively high density or non-residential zoning and more intense public service provision (for services which may be differentiated spatially) per area of land.

A.2.3 Revenue - module no. 16

A.2.3.1 Assumptions

(a) Individuals are aware of the prices, equal to factor costs per unit of input, of individual public services for the past period, and employ these prices in their budget allocation.

(b) The size of the public budget is therefore determined directly by the allocation of individual household budgets, i.e., it is the sum of the individual allocations.

(c) Public revenue may be raised in two ways - through property taxes and income taxes.

(d) The property tax rates may differ for land and buildings.

(e) The income tax is raised according to a formula which includes deductions for family size, on income above some minimum level.

(f) The formula is set by an external government, i.e., it cannot be modified by the local public body.

(g) The income tax is subtracted from incomes to arrive at a disposable income which is used in the household allocation.

(h) Some share of income tax revenue re-enters the urban system through transfers to the local public body. Such transfers may in part be global and in part tied to specific services.

(i) The income tax is raised from the household sector only.

A.2.3.2 Model

$$R = R_p + R_y$$

$$R_p = \sum_j T_{Pt} (V^i_{tj} + V^r_{tj}) + \sum_j T_{Pb} \cdot V^r_{bj}$$

$$R_y = \sum_i T_{yi} \cdot Y_i$$

$$T_{yi} = T^{max}_y - (T^{max}_y - T^{min}_y)^{-k_1\{Y_i - Y^{min} - K_2(FS_1 - 1)\}}$$

where

R = total revenue of the local public body

R_p = revenue from property tax

R_y = revenue from income tax

T_{pt} = property tax rate on land

T_{pb} = property tax rate on buildings

T_{yi} = income tax rate for individual i

T^{max}_y = maximum income tax rate

T^{min}_y = minimum income tax rate

V^i_t = value of industrial land in sector j

V^R_t = value of residential land in sector j

V^r_{bj} = value of residential buildings in sector j

Y_i = income of household i

Y^{min} = minimum income level subject to taxation

K_1 = marginal tax rate

K_2 = deduction per dependent

FS = family size of household i

3.2.3.3 Comments and questions to be examined

(a) What are the relative effects of variations in steepness and level of the income tax rate and level of the property tax rate upon

i) the allocation of household budgets;

ii) the allocation of the local public body budget.

(b) What are the relative effects of the two types of tax on the distributions of personal income, public services and transport costs, assuming that

i) the burdens are distributed differently between the two taxes but that there are no differences in the local public body spending behaviour (i.e., the total income tax yield goes to the local public body as a general supplement and exactly displaces property tax receipts) or alternatively,

ii) that the local public behavior differs for the two types of receipts because of intergovernmental formulas, i.e., share of yield returned and tying to specific services. The distribution of burdens and the total burden would have to be different in general. The "price" of public services would vary because the distribution of property values would differ for property owners from their current income distributions, so that the marginal utilities and hence the levels of demands would differ.

(c) What are the effects of different spatial distributions and degrees of segregation by income, family type, etc. upon the size of the local public body budget.

A.2.3.4 Possible alternatives and extensions

(a) The perception of the price of public services may be different on the part of individual households than it is on part of the local public body. Specifically, if revenues are raised by an income tax which is fixed, households may perceive variations in service levels as pertaining only to variations in property

taxes (variable costs). How does this divergence in the evaluation of prices affect the system compared with the original version.

(b) The local public body may arrive at a total budget on the basis of considerations which modify the figure arrived at by aggregating individual preferences.

(c) The local public body may seek to achieve stability in expenditures, or in property tax rates, or in some related combination of the two by imposing limits on variations from period to period.

(d) In a model where local public body representatives maximize the probability of re-election in their objective functions the length of time to the next election might enter into the constraints on the budget or the tax rate.

(e) Revenues from transfers from senior levels of government might be tied to self-financed expenditures by type of service. How would such formulas affect the distribution among public services.

(f) The income tax base could be enlarged to cover the earnings of firms. In addition the alternative effects of profit tax, value added tax, excise tax, sales taxes versus the property tax could be examined.

(g) By removing the constraint that the income tax is zero for incomes below the minimum level we can examine the effects of a negative income tax.

A.2.4 Local public body allocation of budget to public services - module no. 15, 17

A.2.4.1 Assumptions

(a) Since households can only "purchase" public services as a composite, the local public body

must allocate its global budget on the basis of maximizing the social utility function subject to costs of production and tied intergovernmental funds.

(b) Externalities do not enter into either individual or representative utility functions.

(c) The unit costs of delivery of public services vary by sector because

   i) the composition of the recipients and the "environments" differ in different sectors, e.g., police protection requires larger amounts of inputs to provide a unit of output in some neighbourhoods than in others because of a greater tendency to criminality on the part of inhabitants associated with differences in socio-economic characteristics or because of the higher level of opportunities e.g., greater amounts of moveable properties;

   ii) the efficiency of distribution depends upon the spatial configuration of the recipients and distribution points - there may be scale economies associated with more concentrated population.

(d) The local public body initially allocates the total budget to different public service types. Within each public service type the local public body decides on the distribution among sectors by maximizing the sum of the utilities of the individual local public body representatives subject to some minimum standards of public service delivery, in terms of attributes, in each sector.

A.2.4.2 Model

maximize U_p

subject to

$$\sum_{i,j} P_{ik} \cdot S_{ij} \geq A_k^{min} \qquad \text{all } k$$

$$\sum_j C_{ij} \cdot S_{ij} \leq R_i \qquad \text{all } i$$

$$\sum_i P_{ik} \cdot S_{ij} \geq A_{kj}^{min}$$

where

U_p = utility function of local public body

P_i = attribute points K per unit of public service type i

S_{ij} = level of public service i in sector j

A_k^{min} = minimum level of attribute k for the city.

A_{kj}^{min} = minimum level of attribute k for sector j

C_{ij} = unit cost of providing service i in j

R_i = revenue available for service i

A.2.4.3 Comments and questions to be examined

(a) Since the prices and levels of public service are sector specific, we can examine the effects of different spatial configurations of services for a given population distribution, where these depend on the facility size and the type of population served, etc.

(b) Since the local public body optimizes on the basis of all the arguments of the constituent utility functions it will tend to duplicate satisfactions derived from private goods unless it is providing goods which have a relatively high content of attributes not included in commodities chosen in the private market, either because the distributions of attributes between public and private goods are disjoint (the assumption in this initial version) or because of economies of scale in the production of public goods.

(c) The size of the public sector (determined by revenues) would depend upon the preferences for attributes of public services relative to attributes derived from other goods, and the relative costs of providing them, except that income tax, since it does not depend upon the allocation of the consumer budget, might raise the size of the public sector above that which is socially optimal.

(d) Where a service delivery involves specific distribution points how are these to be allocated spatially so as to maximize efficiency (in the initial version there are no transportation costs associated with the distribution of goods and services but scale economies are possible).

(e) How does the distribution of services shift between those requiring locationally specific distribution points and non-locational distribution types as a function of scale economies, change in population distribution and in the distribution of land uses and densities and in technical changes in production.

(f) What are the distributional effects of changing minimum service levels by sector.

(g) What in general are the changes in public service distributions and methods of delivery due to changes in distribution of recipients, of economic activities and of the level of technology.

A.2.4.4 Possible alternatives and extensions

(a) What are the effects of various plans for reducing unit delivery costs by merging service areas or, by informal coalitions among public body representatives, by reducing the minimum service level constraints.

(b) In a model in which costs of transportation in distribution of goods and services are considered,

questions of central location versus dispersion facilities could be studied. This analysis could be computationally very difficult because we are dealing with a multiproduct firm so it would probably be necessary, as in the present version, to allocate services after the allocation of the overall budget to individual services.

(c) Representatives might modify the sectoral utility functions to include:

i) the utility functions of other representatives leading to acceptance by them and consequently to greater power for the representative;

ii) the aspects of the personal utility of representative.

(d) Assuming each representative behaves according to his sectoral utility function possibly modified by personal or other weights, the representatives might indulge in trading votes or forming coalitions to maximize their individual utilities with allocation governed by a majority vote.

(e) The representatives might first form coalitions according to historical precedent as modified by recent experience, then they might trade votes.

(f) In an urban area with several local public bodies the effects of spillovers might be examined:

i) on the allocation by vote of the local public body representatives who aggregate individual utility functions of their own constituents with or without bargaining, vote trading, etc.

ii) if all public services are provided locally the effects of differences in population compositions, income levels and scale economies in public service production and of spillovers might be investigated;

iii) if local public bodies are partly specialized, providing some services to one or

more other localities the effects of different pricing schemes could be investigated;

iv) if some public services and/or zoning are provided by a metropolitan public body with an equal number of representatives from each locality in parallel with that proportional representation, and in which

a) the metropolitan government trades revenues or controls votes of the representatives;

b) the metropolitan government raises income tax, property tax, or both and redistributes to the local public body.

(g) Allocation might be made by an authority which

i) directly aggregates individual utility functions;

ii) aggregates local public body utility functions unweighted or weighted by population;

iii) aggregates either of these, weighted by income (re-distributive), or by tax contributions to the authority.

A.2.4.5 Possible alternatives and extensions

(a) If public service distribution facilities are allowed to be durable how does this durability influence the location of activities as compared with the model in which there is no fixed capital.

(b) In such a model what are the appropriate decision rules for scrapping facilities.

A.3 Production - modules 8, 9, 11

A.3.1 Assumptions

(a) With a given plant size, each firm operates with fixed ratios of labour and materials to output.

(b) Change in the level of production is a function of past period price change and past period change in the level of imports or exports by the firm and the commodity produced.

(c) If the combined production of all firms in an industry is greater or less than demand at the domestic price, their product will be exported (at a lower price) or imported (at a higher price). Allocation of imports and exports to firms within an industry is proportional to their shares of production.

(d) Except for producers of housing, all output is sold in each period. Vacant housing units cannot be sold in the succeeding period, however, but they take the place of exports in the determination of current period production.

(e) Demand for factors of production follows directly from decisions on output. Labor and materials in excess or shortage are exported or imported respectively, at wages and prices which are lower or higher than domestic wages and prices, respectively.

(f) There are no transportation costs associated with distribution of output.

A. 3.2 Model

$$\frac{Q_{it}-Q_{i,t-1}}{Q_{i,t-1}} = \frac{K_1(P_{i,t-1}-P_{i,t-2})}{P_{i,t-2}} + \frac{K_2(M_{i,t-1}-M_{i,t-2})}{M_{i,t-2}}$$

$$L_{ijt} = K_{3ij} \cdot Q_{it}$$

$$G_{ijt} = K_{4ij} \cdot Q_{it}$$

where

$Q_{it}, Q_{i,t-1}$ = production in the current and the preceding period, respectively of the output of firm i

$P_{i,t-1}, P_{i,t-2}$ = prices of the output of i in each of the two succeeding periods.

$M_{i,t-1}, M_{i,t-2}$ = imports by i of the commodity produced by it in each of the two preceding periods.

L_{ijt} = labor of type j employed by i in t

G_{ijt} = materials of type j employed by i in t

$K_1, K_2, K_{3ij}, K_{4ij}$ = constants

A.3.3 Comments and questions to be examined

(a) Imports and exports of factors and final products allow all markets to be cleared.

(b) What are the effects upon the stability of domestic production of changes in the speed of adjustment of output to price changes ("K_1").

(c) What are the effects of changes in scale of production (represented by plant size) upon profit levels and stability of production over time. A variety of plant size distributions within industries and of consequent distributions in production costs are possible. Some plants and some entire industries may be able to market all of their products at the export price.

(d) In the absence of a specific treatment of capital, some of the material inputs may be viewed as capital with a one-period life.

(e) What are the effects of technological change, favoring large-scale production, capital-intensive production, etc.

(f) What are the effects on prices generally and upon income distribution of the fixing of the prices of industrial products and of factor prices over several periods. Fixed prices of industrial products might be linked, e.g., to non-price competition in the form of product differentiation, represented by changed attribute weightings of the product associated with each firm.

A.3.4 Possible alternatives and extensions

(a) Over time, firms might be created in an industry where profit levels are above some level for a number of consecutive periods, the plant size of the entrants depending upon the distribution of profit levels in existing firms, etc. Similarly, firms sustaining losses over some number of consecutive periods could be eliminated. It could be investigated how various criteria for such births and deaths affect income. In addition, the effects of subsidies for the creation or maintenance of firms could be investigated.

(b) Firms might be assumed to practice a variety of tactics to increase their market shares. Large firms, e.g., might be assumed to be capable of sustaining losses for a larger number of periods than small firms, etc. Such tactics become even more plausible where plants in several industries may be part of a single firm, with profits and losses being shifted among products.

(c) Distribution and land costs could be introduced. It would then be possible to examine the economies derived by various firms in locating at different points in the urban area. It would be especially

interesting to examine their location at concentrations of other industries closely linked to themselves as suppliers or consumers of their product and inputs, versus dispersion to achieve monopoly gains in their individual market areas.

A.4 Consumption - module no. 4

A.4.1 Assumptions

(a) A mapping is possible from commodity space to attribute space: a commodity may have several attributes and an attribute may be contained in several commodities.

(b) All goods may be measured exhaustively in terms of attributes.

(c) There is no substitutability between leisure and market commodities, i.e., the supplying of labour by each household is fixed.

(d) The household knows the prices, i.e., actual public expenditures per unit, of individual public services.

(e) The household examines the vector of prices for housing, market commodities and public services in the previous period, and on the basis of its income in that period allocates income, which is also the expected income in the present period, to each of the goods where housing is divided into housing goods according to type of house, size of lot and location.

(f) From the preceding allocation the household derives a desired vector of public services and an optimal housing bundle.

A.4.2 Model

$$\text{maximize } U_1 = \sum_j A_{ijs}^{T_{sj}}$$

subject to

$$b_{i1} X_1 + b_{i2} X_2 + b_{i3} X_3 = A_i$$

$$p_1X_1+p_2X_2+p_3X_3 = B_i$$

$$X_{3j} = 0,1$$

$$\sum_j X_{3j} = 1$$

where

U_i = the consumer's utility

A_{ijs} = attribute j accruing to individual i in sector S

T_{sj} = lagged attribute A_j for individuals in S

b_{i1},b_{i2},b_{i3} = the individual's matrixes of weights for converting commodities to "attribute points" for public services, market commodities and housing, respectively.

P_1 = the vector of prices of public services, calculated as expenditures per unit of input

P_2 = the vector of prices of private market commodities

P_3 = the vector of market values of housing types (including land)

X_1,X_2,X_3 = vectors of public services, private market commodities and housing types, respectively.

B_j = the individual's budget

X_{3j} = an element of X_3

A.4.3 Comments and questions to be examined

(a) This set of steps provides an initial vector of demands for public services and housing.

(b) This model provides a framework for not only the income and substitution effects among market goods but also between market and "public" goods, including goods not having the classical public good character but provided by the local public body, e.g., utilities.

(c) What is the effect of changes in the quality of goods, public or private, (in terms of the model, changes in their attribute content) upon desired consumption.

(d) What are the effects of the introduction of new goods.

(e) If there is no commonality among commodities in attributes then the model reduces to the conventional analysis of consumer demand.

A.4.4 Possible alternatives and extensions

(a) In an urban area with several local public bodies, it would be possible to examine the choice by the household among localities of residence according to the attribute levels and tax differences associated with the localities which would be traded off against differences in housing price.

(b) With minor modification, the model could be made to treat public services as a composite good, i.e., the consumer views public services as being provided in fixed proportions, perhaps those which obtained in the previous period.

(c) The framework could be extended to include intertemporal aspects, i.e., where the consumer makes a choice on the basis of a discounted stream of utility. Such a model would probably necessitate including expectations about changes in the location of residence and work place and consequent changes in transportation costs and in

general a calculation of the costs of shifting from one consumer bundle to another.

(d) A manageable way of achieving dynamic effects would be to formulate the utility function in terms of anticipations and aspirations based upon past levels of desired and actual consumption.

(e) The attribute content of some goods might be made to vary according to the presence of certain externalities, specifically, congestion and pollution. This would involve not only introducing the negatives of these externalities as goods but also dealing with complementarity explicitly. It would then be possible to investigate how these externalities influence budget allocations. Consequently, through the influence upon income, it would be possible to evaluate the aggregate amount and the distribution of costs of these externalities.

(f) Goods produced by the household for its own consumption, i.e., with its leisure time, could also be introduced in such an extended framework with prices evaluated at the household's wage rate. It would then be possible, e.g., to have the effects of changing money incomes and market prices on household capital formation and the substitution by the household of capital for labour in the production of services for its own consumption. This would also represent an approach to the determination of labour force participation.

(g) Similarly, it would be possible to examine the substitution between the household's consumption of its own production versus that of the local public body, e.g., in the provision of transportation.

A .5 Housing - modules no. 7, 9

A .5.1 Assumptions

(a) Housing is a set of commodities, one of which is purchased by each household in each period.

(b) All housing is produced and located on lots in each period. The form of the production function for housing is the same as that for other industries.

(c) The location of housing by type and quality depends upon the previous period distribution of lots upon which such housing was located by location, size and value, subject to zoning regulations.

(d) The configuration of market values depends upon the bidding of consumers in relation to the suppliers' variations in degree of monopoly power depending upon relative degree of excess demand for different housing configurations.

(e) In making the initial budget allocation on the basis of expected price, the household chooses a specific housing unit, including lot size and location based upon market values of the previous period.

(g) The individual household bids for a housing bundle are summed by housing bundle to arrive at a configuration of excess demands for the housing stock.

(h) The relative bargaining power of housing suppliers and households depends upon, respectively,

i) the number of "eligible" households i.e., those whose bids are of a level such that the supplier is willing to consider them for negotiations; and

ii) the number of housing units for which the household's bid qualifies it to be considered for negotiation.

(i) The household's initial budget allocation to housing is modified to form its housing bid by subtracting costs of commuting and an evaluation of public service levels in each sector relative to levels assumed for budget allocation.

(j) The price of this optimal housing bundle provides a range of prices within which the household must be able to purchase a housing unit.

(k) Within each such range there exists in the present period a set of housing units, according to their producers' offer prices (expected price for the housing unit, equal to expected production cost plus a mark-up, plus price of the lot). Households bid the same amount on all such housing bundles with an adjustment for location, viz. costs of commutation to place of work and public service levels. On the one side suppliers have a set of bids for each of the housing bundles which they offer while demanders are able to make bids on a number of housing bundles. These relative numbers represent the relative market strength of suppliers and demanders in the bidding process.

(l) The sequence of transactions depends upon the market strength of the suppliers, who choose the highest bidders.

(m) In this manner we proceed through the housing stock until all households are exhausted; either the households must emigrate from the urban area or some housing is left vacant.

A.5.2 Model

$$V_{kt} = H \cdot V_k^p + T_{ki}$$

$$B_{is} = HA_i - P_{is} - W_{is}$$

$$V_k^* = B_K^{max}$$

where

V_k = producer's offer price for housing unit and lot KL

H_p = mark-up for housing

V_k = production cost of house type K

T_k = value of lot associated with housing unit i of type k

B_{is} = housing bid of individual i in sector s

HA_i = budget allocation to housing of individual i

P_{is} = adjustment for public service levels in s

W_{is} = adjustment for transport in s

V_k^* = market value of housing unit and lot K

B_k^{max} = maximum bid

A.5.3 Comments and questions to be examined

(a) How do changes in factor and output prices of housing production, zoning regulations and public service levels and distribution over sectors alter the distribution of housing production by type and location.

(b) How do changes in the prices of non-housing commodities alter the distribution of excess demands, prices and profits by housing type and location.

(c) If producers of housing of specified types receive subsidies on factor costs or output price, how does this affect the distribution of housing production by type and location and the type and location of housing purchased by households of various characteristics.

(d) In a program of housing subsidy where that subsidy is aimed directly at "target populations" how much subsidy is required under various conditions; are such subsidies counterproductive.

(e) What are the changes in housing allocations resulting from changes in the income distribution.

(f) How does allocation of housing change as a result of changes in employment location.

(g) How do alterations in the demand profile for housing alter the density of development.

A.5.4 Possible alternatives and extensions

(a) A more elaborate price expectation formation procedure might be adopted which would include lags, and the prices of a range of housing bundles which might be considered among the most likely of the household to choose. This would be likely to introduce greater stability in the housing market and allow for more general competition among participants on the demand side.

(b) Further along this line, households may be treated as searching hierarchically among types where such search involves information costs. Such a procedure would stem from a model of lexicographic preference orderings or a model including information cost. Such a procedure might be computationally simpler, but it would imply a greater price inelasticity, so one would expect a rapidly changing composition of the housing stock relative to price changes; one could, however, incorporate the costs of changing the housing type as a means of stabilizing the market.

(c) Several producers of housing might be introduced engaging in various forms of price and non-price competition. We might include collusion and monopoly (in terms of number of units held by suppliers) leading to the maximization of expected profit for that group of housing units; and we might also introduce alternative bargaining procedures.

(d) The price arrived at in the housing transition might, by a simple extension, be made to depend upon the relative market strength of the two participants.

(e) In a model with stocks, households might be made to remain in the same housing as in the previous period unless the houses were demolished or if the increased utility due to a move exceeded the utility loss represented by costs of moving and a transaction could be culminated with a supplier. With such a model, it would be possible to examine interactions between the existing housing stocks and new construction.

(f) Further, in such a model investment could be undertaken by a renovation industry. It would be possible to examine how, e.g., changes in the demand profile for housing would alter the relative rates of production in the two industries.

(g) Short of a full fixed capital model, housing as long lived capital could be approximated by varying the production costs to include a penalty for construction on a lot of a housing type other than one existing in the previous period. The same type of development, could, of course, be used for other goods as well.

(h) Alternatively, since housing in the present model is classified by condition, one of these classes could represent new housing while production of other classes of condition would be limited to shifting housing among condition classes or demolition (negative production). We might expect greater instability in the production of new housing because of greater uncertainty about the margin of consumers purchasing such housing which would be transmitted to factor markets.

(i) We might introduce rental and owner markets and examine cross influences among the two in terms of:

i) income and price changes;

ii) life cycle effects

iii) durable capital investment and savings including the effects of price changes on owner occupied housing. The locational effects of the two sectors might also be investigated, e.g., rental housing may be located in areas where there is competition from non-residential uses which may force greater utilization of land in those areas whereas owner occupied housing may tend to occupy more extensive lots.

A.6 Wages and prices - module no. 10

A.6.1 Assumptions

(a) On the basis of changes in levels of domestic production in the preceding periods producers make an initial decision as to level of production in the present period.

(b) This decision in turn given a production function implies a specific level of demand for factors, given previous period prices.

(c) Consumers, similarly, anticipate specific levels of demand for individual goods on the basis of previous period prices, their expectations being equal to those of producers.

(d) The disparity between these levels of supply and demand for each commodity represents a set of excess demands which determine an initial set of prices.

(e) This initial price set is calculated from the previous period price plus an adjustment proportional to the level of excess demand and opposite in sign.

(f) Commodities are imported or exported at fixed prices, which, in general, differ from the "domestic" initial price, accordingly as the levels of excess demand resulting from the initial prices are positive or negative, until supply and demand are balanced.

(g) The final price is a weighted combination of domestic and rest-of-the world prices.

(h) Wages are treated identically to commodity prices, except that the domestic labor supply is fixed; labor may be imported or domestic workers are unemployed, with incomes equal to welfare benefits.

A.6.2 Model

$$P_t^i = P_{t-1}^f \left[\frac{1 + K(D_t^i - S_t^i)}{D_t^i \cdot S_t^i} \right]$$

$$P_t^f = \frac{P_t^i \max(S_t^i, D_t^i) + P_t^m M_t - P_t^x X_t}{\max(S_t^i, D_t^i) + M_t - X_t}$$

where

P_t^i = expected price in period t

P^f = final (market) price

P_t^m, P_t^x = import and export prices, respectively, in t

K = a constant for adjusting previous market price to form expectations

D_t^i = demand in t if P_t^i prevails

S_t^i = supply in t if P_t^i prevails

M_t = imports in t

X_t = exports in t

A.6.3 Comments and questions to be examined

(a) This portion of the model allows for intermediation between a purely cobweb type of model and a simultaneous model. The latter would, in the present situation, be computationally much too awkward. The ficticious "predicted" wages and prices may be thought of as points to which both sides of the market are moving. Accordingly, an alternative solution procedure would be to iterate through this and other steps in connection with a method for seeking convergence in order to arrive at a market-clearing set of prices which did not involve the arbitrary device of perfectly elastic import supply and perfectly inelastic export demand.

(b) What are the effects on price stability and profitability in various industries of changes in import and export prices.

(c) What are the effects on wage stability, employment and labour in-migration of changes in rest-of-the-world wage rates.

(d) What are the effects of the speed of adjustment ("K") of price expectations.

A.6.4 Possible alternatives and extensions

(a) Speed of adjustment in price expectations might be differentiated as between producers and consumers.

(b) As a means of price expectation formation a multi-period lag structure might be incorporated.

(c) Considerations of relative bargaining power might be introduced, e.g., price expectation formation might be asymmetric as between demand and supply side offers, depending upon

  i) the relative number of units on each side;

  ii) maximum entry forestalling considerations, e.g., the producer's power increases as

the domestic wage approaches the import wage level;

iii) bidding procedures - the housing market allocation might be extended, i.e., one would establish a price in each industry in a sequence determined by the relative number of alternative offers by producers and consumers.

A.7 Transportation - module no. 18

A.7.1 Assumptions

(a) Transportation costs are associated only with the residence-to-work trip of the head of household.

(b) The route chosen for the residence-to-work trip is the one which minimizes distance.

(c) There is only a single mode of transportation but there exists a continuous scale of mode quality, which incorporates both comfort and speed.

(d) The price of mode quality varies by its level, specifically the curve of price against mode quality is strictly concave downward.

(e) It is assumed that the traveller on the transportation system chooses a level of mode quality such that the ratio of marginal utilities of mode quality to the composite good equals the inverse of their price ratios.

(f) The schedule of mode price versus quality level is a function of the utilization level of the branch or branches of the transportation system being used.

(g) As a consequence of the above the expenditures on transportation can be taken to depend upon the income of the individual worker and the utilization level of the route between residence

and work place.

(h) Differences in estimated transportation costs, based upon previous period work places are incorporated into the household's housing bid; hence, transportation costs will influence residence location.

A.7.2 Model

$$C_{ijk} = (G_{jk} \cdot D_{jk})^{T_i}$$

$$G_{jk} = \sum_h \left(\frac{U_h}{L_h} - G_t\right)/(k-j+1) \quad h=j,\ j+1,\ldots,k$$

where

C_{ijk} = transport cost for individual i with residence in sector j and workplace in sector k

D_{jk} = distance between j and k along shortest route

U_h = level of utilization (average) of transportation network in sector h lying on shortest route between j and k

T_i = a conversion factor for individual i

U_h = level of utilization of transportation link in sector h along shortest distance between j and k

L_h = land devoted to transportation in h

G_{jk} = level of congestion (average) along shortest route between j and k

G_t = threshold level of congestion

A.7.3 Comments and questions for examination

(a) In the initial version of the model, the transportation system is not an object of public expenditure. Costs, including those of congestion, are borne by users of the system, where cost to the individual is calculated as the average cost to all users of a specific route, adjusted for individual income and price

elasticities of mode choice.

(b) What are the effects of different transportation system patterns, e.g., radial, on land value distribution, level of income, etc.

(c) How do congestion costs and changes in the transportation system affect the price structure of housing.

(d) What are the effects of charging tolls (according to level of congestion on the branch, according to income, according to length of journey, according to destination, etc.) on the distribution of residences and value of residences, on the levels of employment in various industries, on the level and distribution of income, etc.

(e) What are the effects of various policies for expanding the transportation system upon the distribution of housing and production activities, level of income, etc. We might start initially with a uniform transportation capacity in each sector, adding capacity e.g., in a sequence determined by level of congestion and land price in each preceding period.

A.7.3 Possible alternatives and extensions

(a) Discrete modes could be introduced which could be expressed in terms of attributes and prices including time "prices", given the utilization levels, and which could then be entered in the consumer budget allocation as a second-round optimization, the initial choice of level of housing expenditure being given. The choice of mode could then be derived directly from the optimal allocation of money and time budgets.

(b) The population could be allowed to choose an optimal route between residence and work place on the basis of attributes relating to speed, comfort, and out of pocket expense where different sets of modes are available on different routes.

(c) Transportation could be treated analogously to housing in the present version of the model, i.e., the population might choose a single route as part of the optimization based on past prices, then subsequently accept a specific mode on the basis of that level of expenditures, e.g., by dividing up the modes according to the cumulative distribution of expenditure levels.

(d) Allowing discrete modes with prices specific to node pairs would introduce a range of mode price and choice problems

  i) what subsidy to mode(s) would cause the least congestion per passenger

  ii) what are the income distribution effects of such subsidies

  iii) if fixed capital is introduced into the model, what would be the utilization of the facilities and what would be the appropriate timing of replacement of the facilities under various conditions.

A.8 Land - module no. 19

A.8.1 Assumptions

(a) In the long run the value of land is derived from the demand for the output of activities occupying that land.

(b) In the short run, however, some "accounting price" exists which causes adjustment in land use to take place.

(c) This "accounting price" is determined by past levels of value and by the "surplus" derived by activities on the land.

(d) The value of land for industry, the location of which is fixed, is set at zero, i.e., only residential land has a positive price.

A.8.2 Model

$$T_{ij} = K_1 \sum_t \lambda_t T_{ij,t} + K_2 (V^*_{ij,t-1} - V_{ij,t-1})$$

where

T_{ij} = value of lot i of specified size in sector j

$T_{ij,t}$ = value of the lot in past period t

$V^*_{ij,t-1}$ = market value of housing unit on the lot in previous period

$V_{ij,t-1}$ = offer price for housing unit on the lot in previous period

K_1, K_2 = constants

λ_t = lag weights

A.8.3 Comments and questions for examination

(a) What are the effects of a tax on land value alone versus a property tax.

(b) What are the effects of various land policy alternatives on activity distributions and income levels

i) public ownership and leasing of land in different configurations and different proportions of the total land area;

ii) controls on land use by area extent, types and configurations.

(c) What are the effects of different transportation network patterns and mode combinations and congestion levels upon land values.

(d) Under what conditions does the maximization of land value in equilibrium serve as a measure of efficiency of the urban economy; for a given level of aggregate money income what are the

effects on the distribution of utility levels of various distributions of activities and land values.

A.8.4 Possible alternatives and extensions

(a) In the present version, only residential land has an explicit market value. Extension to land as a factor with positive price for the production of commodities, public services and transportation would make it possible to investigate the effects of site rents upon levels and land intensities of production of these outputs in different parts of the urban area.

(b) With the introduction of fixed durable capital and of a market for securities, several additional types of investigation are possible which are of great importance in urban analysis, as follows.

(c) It would be possible to incorporate pricing policies by landlords reflecting expectations of yields from future uses. Present prices might be kept high enough to discourage intensive use in anticipation of future use which could be achieved without large conversion costs.

(d) If the landlord is assumed to have direct control over the type of use on the land, it might be held vacant or developed for low-intensity use in anticipation of such high-intensity subsequent use.

(e) Since land price may vary by lot size, landlords might be represented as following strategies of land assembly for the maximization of rents.

(f) Speculation in land may be represented where price expectations are allowed to vary among landlords.

APPENDIX B:

SYSTEM CHARACTERISTICS AND REQUIREMENTS

B.1 SYSTEM DESIGN

The original model contains several optimization problems involving maximization of public and private utility functions. The theory of mathematical programming provides a rigorous and consistent means of linking them.

Specifically, it is both theoretically and computationally feasible and desirable to link the two levels of optimization by a resource-directive decomposition. The general notion of the decomposition is to determine an allocation of shared resources (attributes of the urban area), such that when the individuals act to maximize their own utilities given that allocation (and the transportation, housing and services it makes possible), the overall utility will be maximized also.

The decomposition would have a definite economic interpretation, since it would, at each of its iterations, set prices on attributes of the urban system and place a value on the public budget. Moreover, the sorts of regulatory constraints that are now dealt with separately could be incorporated explicitly by pricing them out according to a logical scheme.

Optimization is carried out via an iterative procedure: a trial vector of shared services is passed from the master problem to a subproblem, which then optimizes its own utility function subject to the availability of those services. From the optimal solution to the subproblem a vector of shadow prices on the services is obtained (i.e., marginal utilities of additional units of each service), which is passed to the master problem to refine the representation of the aggregate utility function. (Operationally, the shadow

price data are incorporated as a new constraint on the master problem utility maximization.) The procedure terminates at an allocation when no new shadow price data are generated.

As can be seen from Fig. B-1, the subproblem in this case would itself be a non-trivial optimization problem, since it requires that a spatial equilibrium be obtained involving variables that describe housing location and transportation demand. Solution of the equilibrium problem at each iteration of the overall decomposition will itself require a further decomposition stage. There are several approaches which might be taken here, and it may well be that some heuristic method would be most appropriate. One advantage of the overall decomposition approach is that it isolates the spatial equilibrium problem from the rest of the model; the master problem becomes one of optimizing the response of the spatial equilibrium problem, however solved or approximated, to allocation of resources.

The decomposition approach has been successfully applied to modeling supply-demand equilibrium in the U.S. copper industry[1] and to U.S. supply and demand markets for coal.[2]

Intelligent initialization of the decomposition would accelerate convergence. Since the procedure works by accumulating data on the shape of the utility functions in the subproblems, data from a previous solution could provide a good starting point for a new, related problem. Computation time would be reduced by a significant factor. Thus, a sequence of scenarios could be investigated efficiently, provided the sequence planned to take advantage of this effect. Note also that the decomposition could be interrupted

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[1] Brown, Richard W., A Method for Sensitivity Analysis of L.P. Decomposition Equilibrium, with Application to the Copper Industry, MIT Master's Thesis, 1980.

[2] Shapiro, Jeremy F. and White, David E., "Decomposition and Integration of Coal Supply and Demand Models," Technical Report No. 171, Operations Research Center, MIT, March 1980.

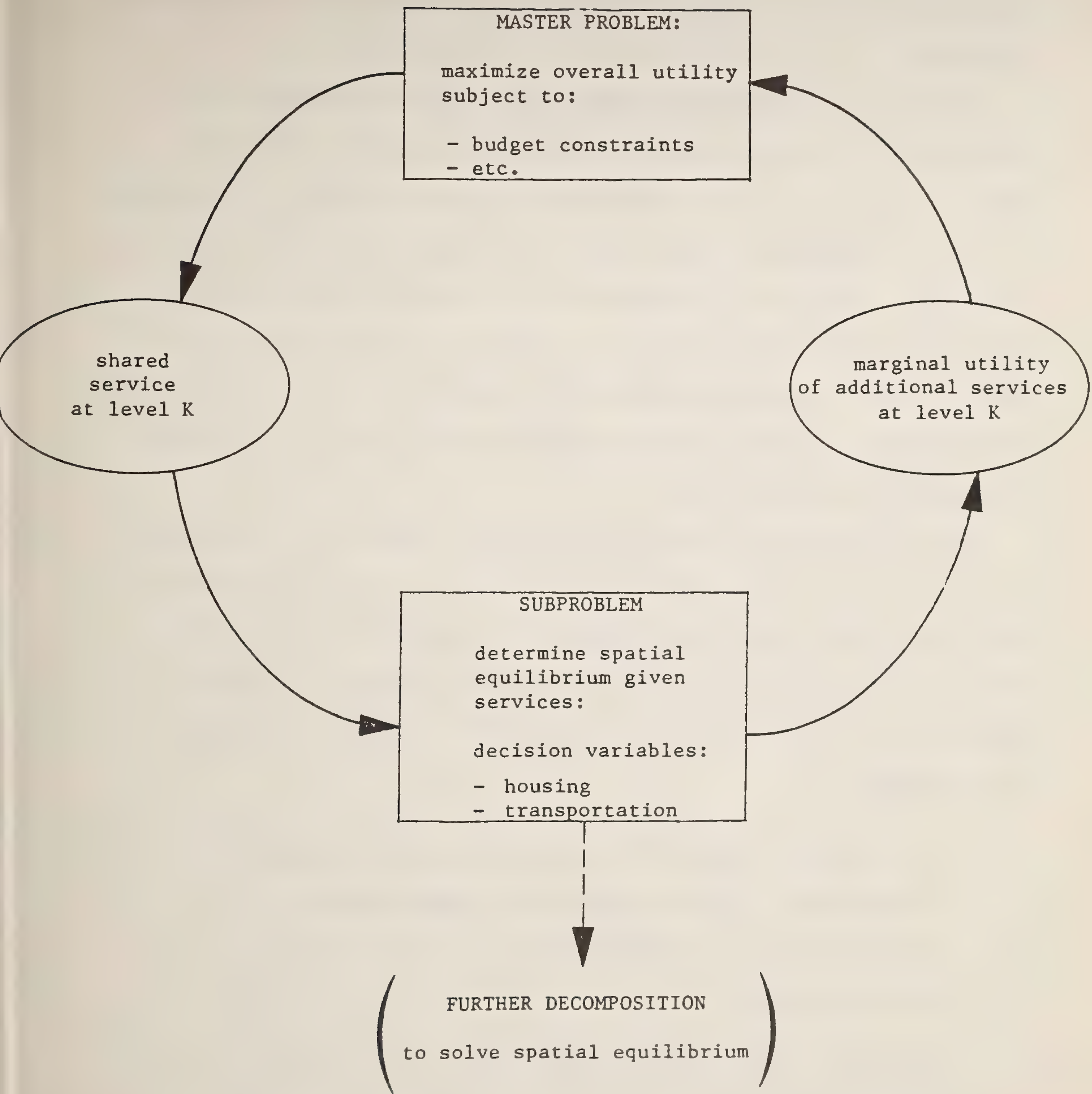

Figure B-1.

SYSTEMS PROBLEM RESOLUTION

at any point before convergence if a given error bound on the solution were acceptable.

For the purpose of model development and testing (particularly in the absence of particular applications), it would be best to keep the number of individual utility subproblems small (less than 50). This implies a simplified demographic representation, with fewer individuals represented and/or fewer geographical divisions within the hypothetical urban area. Aside from the practical advantages of reducing computation time, model size, and data requirements during the development phase, this would provide an opportunity to assess the broad response characteristics of the model, undisguised by excessive detail.

The above discussion establishes a general framework for structuring the model which is rich enough to cover most, if not all, of the issues which the original model seeks to address. Nevertheless, considerable work will have to be done in defining the precise extent of aggregation needed and the structure of the resulting model. The following issues are significant:

- It is essential that the utility function U_p (as described in Section A.2.1.2) be concave if the decomposition is to operate reliably. Concavity is a natural property for any utility function.

- The relationship of transportation and housing to the rest of the model must be further specified. The spatial equilibrium over transportation and housing provides the underpinning of the model.

- The individual utility maximization problems require 0-1 variables in order to choose between different housing categories. It is essential that these models be sharply defined, since they are the core of the optimization.

B.2 IMPLEMENTATION

Given the relatively small size of the contract, and the complexity of the model as envisioned, it is essential not to attempt too much in initial implementation. The focus should be on demonstrating the existence of a useful, operable model -- operable in the sense that the model works reliably, and useful in the sense that it can be used consistently within the limits of its implementation to obtain valid results.

This suggests that the specification of all optimization models be fixed as precisely as possible, as early as possible, since the decomposition procedure will inevitably be model-specific to some extent. At the very least, it is necessary to determine which variables will participate directly in the decomposition procedure as past prices, etc., so that the procedure can be built around them. Once this is done, the decomposition module and the generation module can be designed in tandem. The resulting system should permit, at most:

- Numerical modifications to optimization models, via an interface with the generation module;
- Changes in the number of individual utility submodels, within limits;
- Few if any changes to the structure of the optimization models.

In the course of implementation it may be possible to relax the third restriction in this list, but this should not be taken as a primary design objective.

The decomposition procedure will require the use of a highly flexible linear programming package such as MPSX/370 with the Extended Control Language (ECL) feature. Since ECL is based on PL/1, the other modules would best be written in that language. Development will require a programmer familiar with PL/1 and with the theory of L.P. decomposition.

The generation module will involve a fair amount of system programming effort. Broadly speaking, it must convert user specifications of the model into the form required by the decomposition procedure (MPSX format). Obviously, the more flexibility in model specification required by the user, the more elaborate the generation module will be.

The following general scheme would be appropriate (see Figure B-2). A complete description of the model for some base-case would reside on a permanent file, in readable format. (There might be many such files, corresponding to a variety of base cases.) An interactive inquiry routine would allow the user to examine the characteristics of the model and specify changes (primarily data-related, not structural). These changes would be merged with the base-case representation to form a new representation of the model (thus leaving the old representation intact); this would be the primary mechanism for creating model variants.

Any such model file (whether permanent or created temporarily from the merging operation) would provide the input to the Generation module, which would produce from it a set of MPSX input files representing the optimization models for the decomposition. The generation module would also produce a file describing any evolution in the data of the updating rules over the periods under consideration.

An essential design step will be to establish, as precisely as possible, limits on the two types of changes that will be made in using the model:

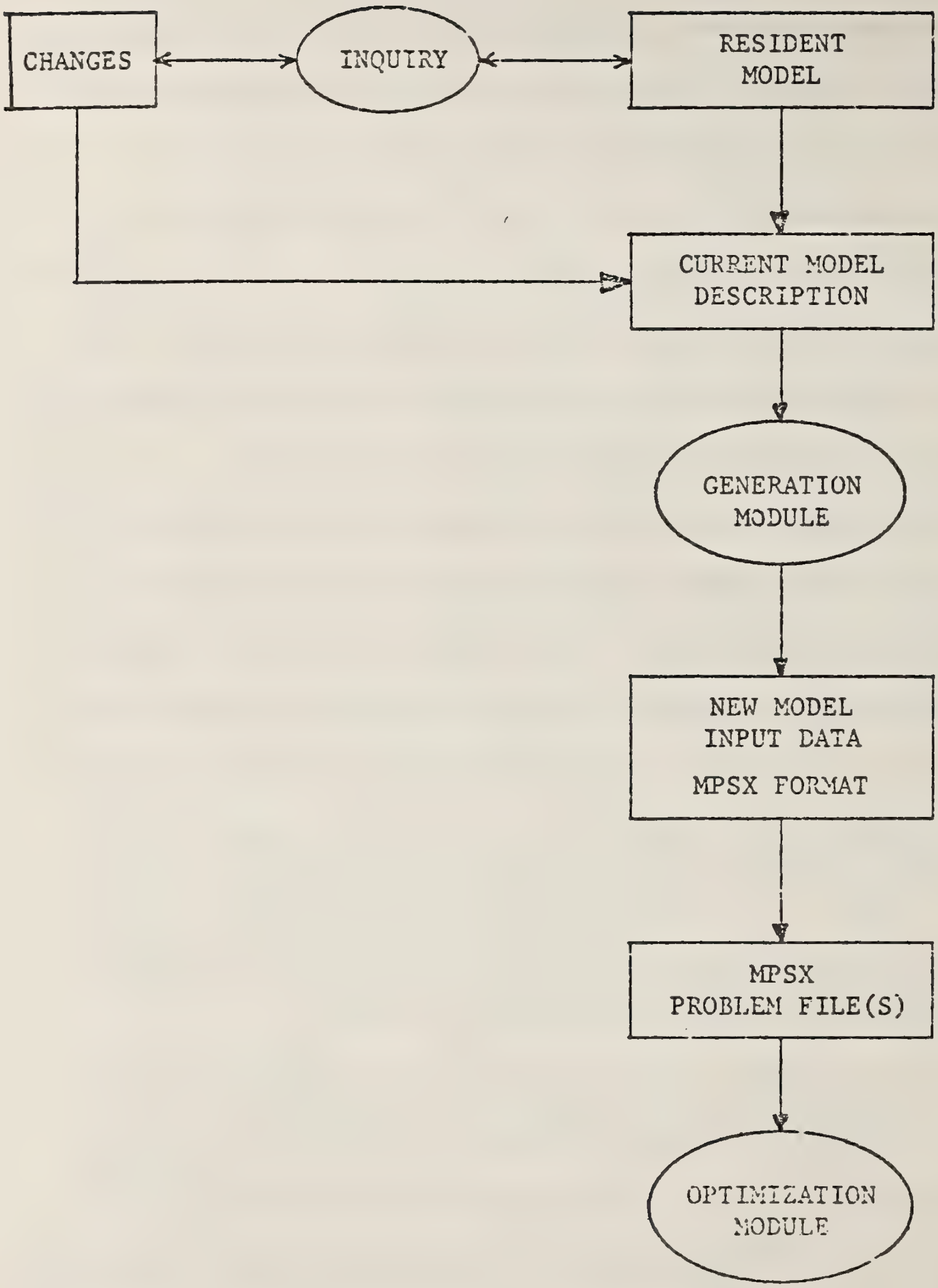

Figure B-2.

GENERAL SCHEME OF COMPUTER OPERATIONS

- changes to the data from run to run;
- changes to the data (via updating) from period to period within a run.

The scope of the first sort of change will largely determine the complexity of the model description and generation routines just mentioned; the scope of the latter sort of change will determine the nature and complexity of the updating routines.

Serious thought needs to be devoted to describing (and prescribing) the sorts of scenario testing sequences that will be employed, to take advantage of computational efficiencies noted above. This sort of usage will require direct modification of MPSX data files (rather than the model description files). Among other things, the routines which allow users to modify models on which the decomposition has already been performed must ensure that the changes correspond to real model features and that they do not destroy essential model structure. This suggests that an early decision must be made to delimit the types of changes that scenario testing will involve.

We should also note in passing that some attention should be given to the structure of the data files for the system, to ensure that they will be readily compatible with any data verification or analysis packages that may subsequently be employed.

Development would best be carried out under IBM 370/CMS. The interactive mode will be highly desirable during system development, and in regular use as well, for scenario testing and, if desired, structured user-input into the modeling and optimization process. The virtual machine size required will be 1.5 - 2 megabytes. A batch or TSO system could also be used, less conveniently.

APPENDIX C:
SPECIFICATION OF THE MODULES

INDEX TO APPENDIX C

Note: Definitions of mnemonics are given in the Mnemonic Dictionary, Appendix D.

Module number 1

Utility aggregation by local public body

Input variables

POP (T, OT, SL, AL, FS, SIEL, S, POW)
PSTAC (OT, AL, SL, PST, AT)
PSL (T, S, PST)
LP (S)

Model

Part # 1: Utility function for public services

$$UFLPB\ (S,AT) = POP(S)^{KPOP} * ULPR(S,AT)$$

where

$$ULPR(S,AT) = \sum_{PST=1}^{12} \frac{PSL(S,PST) * PSTAC(OT,AL,SL,PST,AT)}{POP(T,OT,SL,AL,FS,S,POW)}^{IPS*B(S,M,1)}$$

$$B(S,M) = JPS1(AT,M) \sum_{j\ \frac{1}{2}\ -2}^{-(T1-T2)} \sum_{K\ \frac{1}{2}\ -1}^{-(j-1)} PSS1(-K,AT,M)$$

$$*PSS2\ (-(j-K),\ AT,M) * AL\ (-J,S,AT,M)$$

$$- \sum_{T=1}^{-T1} PSS1\ (-T,AT,M) * AL\ (-T,S,AT,M)$$

$$+ 1$$

Part #2: Utility for regulatory constraints: pollution regulations

$$UFRCP(S) = POP(S) * CRCI * LP(S)^{IPS*B(S,M,1)} + KP(S)$$

where

$$KP(S) = [KRC1 * X1 + KRC2 * X2 + KRC3 * X3 + KRC4]$$

$$X1 = \sum_{OT=1}^{6} \frac{POP(T,OT,SL,AL,FS,S,POW)}{\text{Total population of city}}$$

$$X2 = \sum_{AL=1}^{6} \frac{POP(T,OT,SL,AL,FS,S,POW)}{\text{Total population}}$$

$$X3 = \sum_{SL=1}^{3} \frac{POP(T,OT,SL,AL,FS,S,POW)}{\text{Total population}}$$

Part #3: Utility function for regulatory constraints: zoning regulations

$$UFRCZ(S) = POP(S)*CRCI*\sum_{ZT=1}^{5} UZ(S,ZT)$$

where

$$UZ(S,ZT) = SKZ(ZT)* \frac{TZA(ZT)}{TA}^{KZ(1,ZT)}$$

$$* \frac{A(S,ZT)}{TA(S)}^{KZ(2,ZT) -KZ(3,ZT)} \quad \frac{A(S,ZT)}{TA(S)}$$

$$TA(S) = \sum_{ZT=1}^{5} A(S,ZT)$$

$$TZA(ZT) = \sum_{S=1}^{12} A(S,ZT)$$

$$KZ(J,ZT) = KKZ(J,ZT,1) * X1 + KKZ(J,ZT,2) * X2 + KKZ(J,ZT,3) * X3 + KKZ(J,ZT,4) * X4 + KKZ(J,ZT,5)$$

Default value for KZ(J,ZT) = 0

where X1, X2 and X3 are as previously defined and

$$X4 = \sum_{FS=1}^{4} \frac{POP(T,OT,SL,AL,FS,S,POW)}{\text{Total population}}$$

KZ(1,ZT) relates actual distribution of land uses in the urban area as a whole to the utility derived from such distribution.

KZ(2,ZT) and KZ(3,ZT) do the same for land use in the household's own sector. The relative size of the two determines the point where an additional share of a specific use in the sector (holding the urban area distribution constant) adds no further utility.

Output

ULPR(S,AT)
UFRCP(S)
UFLPB(S,AT)
UFRCZ(S)

<u>Module number 2</u>

Zoning regulations

Input variables

A(S,ZT)
POP(T,OT,SL,AL,FS,SIEL,S,POW)
KKZ(J,ZT,I)
SKZ(ZT)

Model

The following function must be maximized:

$$UZ(S,ZT) = SKZ(ZT) * \frac{TZA(ZT)}{TA}^{KZ(1,ZT)} *$$

$$\frac{A(S,ZT)}{TA(S)}^{KZ(2,ZT0-KZ(3,ZT)\ \frac{A(S,ZT)}{TA(S)}}$$

where TA(S), TZA(ZT), KZ(J,ZT) are as previously defined in Part #3 of Module #1,

subject to the following constraints:

A. $LLP(S,ZT) \leq \frac{A(S,ZT)}{TA(S)} \leq ULP(S,ZT)$

for all sectors and zoning types

$$LLP(S,ZT) = LL * \frac{TZA(ZT)}{TA}$$

$$ULP(S,ZT) = LU * \frac{TZA(ZT)}{TA}$$

B. $\sum_{S,ZT} \frac{A(S,ZT)}{TA(S)} = 1$

Output

A(S,ZT)
UZ(S,ZT)

Module number 3

Land percentage

Percentages of urban land used for residential industrial, commercial and other purposes are calculated.

Input variables

RES(U,S,ZT,LS,LSV)
COML(U,S)
INDL(U,S)
TRNSL(S)

PUBSEL(S)

PUBSIL(S)

Model

Part #1: Residential

$$\sum_{S=1}^{12} \sum_{ZT=3}^{4} A(S,ZT) = \sum_{S=1}^{12} \tfrac{1}{4} * \sum_{U=1}^{1} \sum_{ZT=3}^{4} \sum_{LSV=1}^{6}$$

$$RES(U,S,ZT,1,LSV) + \tfrac{1}{2} * \sum_{U,ZT,LSV} RES(U,S,ZT,2,LSV)$$

$$+ 1 * \sum_{U,ZT,LSV} RES(U,S,ZT,3,LSV)$$

$$+ 2 * \sum_{U,ZT,LSV} RES(U,S,ZT,4,LSV)$$

$$+ 3 * \sum_{U,ZT,LSV} RES(U,S,ZT,5,LSV)$$

$$+ 5 * \sum_{U,ZT,LSV} RES(U,S,ZT,6,LSV)$$

Part #2: Commercial

$$\sum_{S=1}^{12} A(S,1) = \sum_{S=1}^{12} \sum_{U=1}^{2} COML(U,S)$$

Part #3: Industrial

$$\sum_{S=1}^{12} A(S,2) = \sum_{S=1}^{12} \sum_{U=1}^{2} INDL(U,S)$$

Part #4: Other

$$\sum_{S=1}^{12} A(S,5) = \sum_{S=1}^{12} TRNSL(S) + PUBSEL(S) + PUBSIL(S)$$

$$\sum_{S=1}^{12} TA(S) = \sum_{S=1}^{12} \sum_{ZT=1}^{5} A(S,ZT)$$

Output

A(S,ZT)

Module number 4

Population housing bid and allocation to public service

Input variables

LCPG(OT,AL,SL,CGT,CPT)
LCIPG(OT,AL,SL,CGT,CPT)
LCS(OT,AL,SL,ST)
PSL(T,S,PST)
HE(OT,AL,SL,FS,HT)
PPG(CGT,CPT)
PIPP(CGT,CPT)
PPU(S,PST)
PPS(T,ST)
WAGE(OT,AL,SL)
POP(OT,AL,SL,FS,POR,POW)
IS(S,CGT,CPT,FACS)
IFRODG(T,CGT,CPT,FACS)
N(OT,AL,SL,FS)

Model

Subpart #1: Utility curves for specific attributes

AT = 1 through 5

$$UFA(AT) = AP(AT)^{B(S,M,2)}$$

where

$$AP(AT) = \sum_{CGT,CPT} GTA(OT,AL,SL,CGT,CPT,AT)$$
$$* [LCPG(OT,AL,SL,CGT,CPT) + S1*LCIPG(OT,AL,SL,CGT,CPT)] +$$
$$\sum_{ST} GTAC(OT,AL,SL,ST,AT) * LCS(OT,AL,SL,ST) +$$
$$\sum_{PST} PSL(T,S,PST) * PSTAC(OT,AL,SL,PST,AT)$$
$$\sum_{HT} HE(OT,AL,SL,FS,HT) * HAC(OT,AL,SL,FS,AT,HT)$$

Binary switch variable S1 set to zero initially to eliminate imported goods factor.

Part #2: Optimize the attribute utility function for each population sector (OT,AL,SL,FS), S1=0;

$$\text{Max:} \quad \sum_{AT=1}^{5} UFA(AT)$$

Subject to:

$$\text{A.} \quad \sum_{CGT,CPT} LCPG(OT,AL,SL,CGT,CPT)* PPG(CGT,CPT)$$
$$+ S1 * [LCIPG(OT,AL,SL,CGT,CPT)* PIPG(CGT,CPT)]$$
$$+ \sum_{PST} PPU(S,PST) * PSL(T,S,PST)$$
$$+ \sum_{ST} PPS(T,ST) * LCS(OT,AL,SL,ST)$$
$$+ \sum_{HT} HE(OT,AL,SL,FS,HT)$$
$$+ CCTW(OT,AL,SL,S,POW)$$
$$+ ITX(OT,AL,SL) \leq WAGE(OT,AL,SL)$$

where

$$CCTW(OT,AL,SL,S,POW) = \sum_{TOD} ISTC(TOD,S,POW)$$

B. $AP(AT) \leq AML(T,OT,AL,SL,AT)$

C. $S1*CPG(OT,AL,SL,CGT,CPT) \leq S1*EAG(CGT,CPT,OT,SL,AL)$

Part #3: Sum demand for each commodity and service over all sectors.

$$\sum_{OT,AL,SL} [LCPG(OT,AL,SL,CGT,CPT) + LCS(OT,AL,SL,ST)] *$$

$$\sum_{FS,SIEL,POR,POW} POP(OT,AL,SL,FS,SIEL,POR,POW)$$

The total amount of consumer goods supplied is

$$\sum_{CGT,CPT} TSCG(T,CGT,CPT) =$$

$$\sum_{S,FACS} IPRODG(T,CGT,CPT,FACS) * IS(S,CGT,CPT,FACS)$$

The amount supplied is divided equally or by function EAG(CGT,CPT,OT,AL,SL) among the population. Reoptimize the attribute utility function in Part #2. Set S1 equal to 1 to include imported goods.

Part #4: Demand for different housing types

$$HSD(T,S,HT,HV,HC) = \frac{HE(OT,AL,SL,FS,HT)}{HE(OT,AL,SL,FS,HT^*)}$$

where HT* is the one HE which is non-zero.

Part #5: Tax rate

Allocation by population to public services

$$\sum_{PST} PPU(S,PST) * PSL(S,PST)$$

Total allocation to public service is

$$R = \sum_{S,PST} \sum_{OT,SL,AL,SIEL,FS} PPU(S,PST) * PSL(S,PST) * N(OT,AL,SL,SIEL,FS)$$

$$ITR = \frac{R}{TVUP}$$

Output

HE(OT,AL,SL,SIEL,FS,HT)

HEFI(OT,AL,SL,SIEL,FS)

ITR

<u>Module Number 5</u>

Price of public services

Input variables

PSL(S,PST)

PSE(T,S,PST,PSST)

Model

Part #1:

$$PPU(S,PST) = \sum_{PSST} \frac{PSE(T,S,PST,PSST)}{PSL(S,PST)}$$

Output

PPU(S,PST)

Module number 6

Income tax

Input variables

WAGE(OT,AL,SL,SIEL)

Part #1:

$$ITR = ITR^{MAX} - (ITR^{MAX} - ITR^{MIN}) * - ITXX(WAGE-MI)$$

where

$$ITXX = ITR(WAGE-MI) - KIT * (FS-1)$$

Output

ITX

Module number 7

Household location

Input variables

HEP(S,HT,HV)
HE(OT,AL,SL,SIEL,FS,HT)
HEPI(OT,AL,SL,SIEL,FS)
HS(T,S,HT,HV,HC)
HPROD(S,HT,HV)

Model

For each housing type divide it into categories according to price bid

$HE(OT,AL,SL,FS,HT,HC,LS)$

$HE_1 < HE_2 < HE_3 < HE_4 < HE_5$ all HT

Similarly for each housing type divide it into categories depending on the producer's offer price

$HAV(S,HT,HC)$

$HV_1 < HV_2 < HV_3 < HV_4 < HV_5$

where $HV_i = HE_i$

For each house within each selling category, compute the "adjusted price or value" to each buyer in the same buyer category which is (S is his present sector)

$HE(OT,AL,SL,FS,HT,HC) = HE(OT,AL,SL,FS,HT,HC)$
$- PSDF(S,K) - WTD(K,S)$

Only include these new HES which were within the original range.

This then gives a set of bids for each house to be sold. These are

HE1
HE2
HE3
⋮
HEM

Now weight each HE1 by the number of other bids, r, which that buyer makes

$HEI = HEI + f(r)$

For each seller $W = \sum_{I} HEI$ is the weight attached to to that housing unit.

Order all housing units by weight (within category) and start assignment of those with highest weight to highest bidder and continue until either

(a) housing stock exhausted, causing out migration

(b) buyers exhausted, causing surplus housing inventory.

Output

POP(T,OT,SL,AL,FS,S,POW)
HPT(S,HT,HC,HV)

<u>Module number 8</u>

Projected industry production and demand for commodities and services

Input variables

PPG(T,CGT,CPT)
IS(S,GGT,CPT,FACS)
WAGEH(T,OT,SL)

Part #1: Labor employed by physical sector S

$$ILABD(S,OT,SL) = \sum_{CGT,CPT,FACS} ILABR(CGT,CPT,OT,SL,FACS) * IPRODG(T,CGT,CPT,FACS) * IS(S,CGT,CPT,FACS)$$

$$\text{Material used} = IMATD(T-1,GT,PT,IOE) = IMATR(GT,PT,CGT,CPT,IOE,FACS) * \sum_{CGT,CPT,FACS} IPRODG(T-1,CGT,CPT,FACS)*IS(S,CGT,CPT,FACS)$$

Location of industry by physical sector S.

IS(S,CGT,CPT,FACS)

Part #2: Wages from the previous period labour market

WAGEH(T,OT,SL)

Part #3:

(a) Previous period production of each consumer good type.

$$TPRODG(T-1,CGT,CPT) = \sum_{S} IPRODG(T-1,S,CGT,CPT)$$

(b) Previous period demand for each consumer good type.

$$TDEMG(T-1,CGT,CPT) = \sum_{OT} \sum_{SL} DEMG(T-1,CGT,CPT,OT,SL) * POP(T-1,OT,SL,AL,FS,SIEL,POR,POW)$$

$$\sum_{AL;FS,SIEL,POR,POW}$$

Part #4: Price of materials used in production (from previous period)

PPM(T-1,GT,PT)

Model

The new production level is determined by:

$$\frac{IPRODG(T,CGT,CPT,FACS) - IPRODG(T-1,CGT,CPT,FACS)}{IPRODG(T-1,CGT,CPT,FACS)}$$

$$= \frac{KIP1* (PPG(T-1,CGT,CPT) - PPG(T-2,CGT,CPT))}{PPG(T-2,CGT,CPT)} +$$

$$\frac{KIP2\ (LCIPG(T-1,CGT,CPT,FACS)\ -\ LCIPG(T-2,CGT,CPT,FACS))}{LCIPG(T-2,CGT,CPT,FACS)}$$

Part #5: Total supply of consumer goods

$$TSCG(T,CGT,CPT) = \sum_{S,FACS} [IPRODG(T,CGT,CPT,FACS) + IINV(T,CGT,CPT,FACS)] * IS(S,CGT,CPT,FACS)$$

Initially it will be assumed that no inventory of products will exist

Part #6: Price per unit of consumer good

$$PPG(T,CGT,CPT) = PPG(T-1,CGT,CPT) * + \frac{KPPG*TDEMCG(T,CGT,CPT)*TSCG(T,CGT,CPT)}{TDEMCG(T,CGT,CPT)*TSCG(T,CGT,CPT)}$$

Part #7: Minimize the following function

$$\Sigma PPM(T,CGT,CPT)*IMATD(S,CGT,CPT,IOE) + \Sigma WAGEH(T,OT,SL)*ILABD(S,OT,SL)$$

Output

Predicted TPRODG(T,CGT,CPT)
Predicted IMATD(S,CGT,CPT,IOE)
Predicted ILABD(S,OT,SL)

Module number 9

Projected housing industry production of new housing

There are two important parts to this industry:

Input variables

(a) Labor employed and material used in previous two periods

HLABD(T,S,OT,SL)
HMATD(T,HT,HC,GT,PT)

(b) Location of housing by physical sector, s.

HAL(T,S,HT,HC,LS,LSV)

Wages from the previous period labour market

WAGEH(T,OT,SL)

Price of materials used in production (from previous period)

PPM(T-1,GT,PT)

Number of vacant lots RESL(UA,S,ZT,LS,LSV); their size and price RESLV(S,LS,SLV)

Material requirements for housing
HMATR(HT,HC,GT,PT)

Model

Part #1: Offer price for housing unit

HSP(S,HT,HC) = KL*HPRODP(T-1,S,HT,HC)

where cost of production

HPRODP(T-1,S,HT,HC) = HLABR(T-1,S,OT,SL)*
WAGEH(T-1,S,OT,SL) + HMATR(T-1,HT,HC,GT,PT)*
PPM(T-1,GT,PT)

Level of production

$$\frac{HPROD(T,S,HT,HC) - HPROD(T-1,S,HT,HC)}{HPROD(T-1,S,HT,HC)}$$

$$= KHP1[HSP(T-1,HT,HC) - HPT(T-1,HT,HC) - LV(T-1,S,HT,HC)] + \frac{KHP2[HINV(T-1,HT,HC) - HINV(T-2,HT,HC)]}{HINV(T-2,HT,HC)}$$

Input requirements

HLABD(T,S,HT,HC,OT,SL) = HLABR(T,OT,SL,HT,HC) * HPROD(T,S,HT,HC)

HMATD(T,HT,HC,GT,PT) = HMATR(T,GT,HT,HC) * HPROD (T,S,HT,HC)

Part #2: Distribution of housing over different lot sizes.

Given

HAL(T,S,HT,HV,LS,LSV)

the previous distribution of housing

Normalize this distribution, or Monte-Carlo technique to select from that distribution (given HT and HV) the LS and LSV of

HPROD(T,S,HT,HV,HC)

Thus the new distribution of housing over lots LS and LSV is the same as HAL(T,S,HT,HV,LS,LSV).

Part #3: Offer price of housing and lot

HVA(T,S,LS,HT,HC) = HSP(S,HT,HC) + LV(S,LS)

Output

HPROD(T,S,HT,HV)
HLABD(T,S,OT,SL)
HMATD(T,HT,HV,GT,PT)
HAL(T,S,HT,HV,LS,LSV)
HVA(T,S,LS,HT,HC)

Module number 10

Predicted wage and price levels

Part #2:

A. Prices

Input variables

POP(T,OT,SL,AL,FS,POR,POW)
DEMCG(T,CGT,CPT,OT,SL)
IPRODG(T,CGT,CPT,FACS)
IS(S,CGT,CPT,FACS)
PPG(T,CGT,CPT)

(1) For each population sector and industry, demand for good

$$\sum_{CGT,CPT,OT,SL} DEMCG(T,CGT,CPT,OT,SL) * \sum_{AL,FS,POR,POW} POP(T,OT,SL,AL,FS,POR,POW)$$

(2) For the industry production

IPRODG(T,CGT,CPT,FACS)

(3) Previous price of each good

PPG(T-1,CGT,CPT)

Part #2: Aggregate demand for goods over S sectors

Model

New price = old price plus a function of the difference between supply and demand.
Total domestic demand for each consumer good and total domestic supply of each consumer good.

$$TDEMCG(T,CGT,CPT) = \sum_{OT,SL} DEMCG(T,CGT,CPT,OT,SL) *$$

$$\sum_{AL,FS,POR,POW} POP(T,OT,SL,AL,FS,POR,POW)$$

$$TSCG(T,CGT,CPT) = \sum_{S,FACS} IPRODG(T,CGT,CPT,FACS)$$

and

$$PPG(T,CGT,CPT) = PPG(T-1,CGT,CPT) *$$

$$+ \frac{KPCG(CGT,CPT)*[TDEMCG(T,CGT,CPT)-TSCG(T,CGT,CPT)]}{TDEMCG(T,CGT,CPT)*TSCG(T,CGT,CPT)}$$

Output

(1) Predicted new price of goods.

PPG(T,CGT,CPT)

B. Wages

Input variables

(1) Demand for each labour occupation and skill type by each industry and public service.

(a) Housing HLABR(HT,HV,OT,SL)

(b) Industry ILABR(T,CGT,CPT,OT,SL,FACS)

(c) Public sector PSLABR(T,S,PST,OT,SL)

(d) HPROD(T,S,HT,HV)

(e) PSL(S,PST)

(2) Supply of labor for each sector by each occupation and skill type (from individual time utilization sub-module).

$$\sum_{\substack{AL,FS,SIEL,POW \\ SIEL>0}} POP(T,OT,SL,AL,FS,SIEL,POW)$$

(3) Previous wage for each occupation and skill type.

WAGEH(T-1,S,OT,SL)

Model

Aggregate demand and supply for each occupation and skill level.

New wage = Old wage plus increment depending upon the disparity between projected demand and supply levels.

Demand for labour is calculated as follows:

$$TLABD(T,S,OT,SL) = \sum_{HT,HV} HLABR(HT,HV,OT,SL) * HPROD(T,S,HT,HV) +$$

$$\sum_{CGT,CPT,FACS} ILABR(T,CGT,CPT,OT,SL,FACS) * IS(S,CGT,CPT,FACS) * IPROD(T,CGT,CPT,FACS) +$$

$$\sum_{PST} PSLABR(T,S,PST,OT,SL) * PSL(S,PST)$$

Supply of labor is given by:

$$TLABS(T,S,OT,SL) = \sum_{AL,FS,SIEL,POW} POP(T,OT,SL,AL,FS,SIEL,S,POW)$$

thus:

$$WAGEH(T,S,OT,SL) = WAGEH(T-1,S,OT,SL)* + \frac{KWGH(OT,SL)*[TLABD(T,S,OT,SL)-TLABS(T,S,OT,SL)]}{TLABD(T,S,OT,SL)*TLABS(T,S,OT,SL)}$$

Output

Predicted new wages for occupation and skill

WAGEH(T,S,OT,SL)

Module number 11

Final determination of industrial production and demand for goods and services

Rerun module #8 to recalculate IPRODG,IMATD and ILABD.

Module number 12

Final determination of industry production of new housing.

Rerun module #9 to obtain final values of HLD, HLABD,HMAID.

Module number 13

Price and wage levels.

Rerun module #10 to obtain final values of PPG and WAGEH.

Module number 14

Population choice of commodities and services given housing choice

Rerun module #4, part #2 to obtain LCP and LCS

Module number 15

Local public body allocation to public services

Input variables

ECI(T)
PTS(PST)
FTS(PST)
PSTAC(PST,AT)
PSE(T,PST,PSST)
PSD(T,S,PST)
PSMAP(T,AT)

Model

Part #1:

Maximize: UFLPB(S,AT)

subject to:

$$\sum_{S,PST} PSTAC(PST,AT)*PSD(T,S,PST)>PSMAP(T,AT)$$

$$\sum_{PST} PSA(T,PST)\leq ECI(T)+FTS(PST)+PTS(PST)$$

where

$$PSA(T,PST) = \sum_{S,OT,SL} PSLABD(T,S,OT,SL)*WAGEH(T,OT,SL)$$

$$+ \sum_{S,GT,PT,IOE} PSMATD(T,S,GT,PT,IOE)*IMATC(T,GT,PT,IOE)$$

Output

PSA(T,S,PST)

<u>Module Number 16</u>

Local public body income

Input variables

PTS(PST)

FTS(PST)

RESL(U,S,ZT,LS,LSV)

RESLV(S,LS,LSV)

COML(U,S,LSV)

COMLV(LSV)

INDL(U,S,LSV)

INDLV(LSV)

HS(T,S,HT,HV,HC)

HSV(S,HT,HV,HC)

CS(S,CGT,CPT)

CSV(S,CGT,CPT)

IS(S,CGT,CPT,FACS)

ISV(S,CGT,CPT,FACS)

PTR(PRPT,ZT)

AR(PRPT,ZT)

Model

Part #1: Endogenous city income from land

$$ECIL = PTR(1,2)*AR(1,1)* \sum_{LSV} [\sum_{U,S} IINDL(U,S,LSV)$$

$$*INDLV(LSV) + PTR(1,2)*AR(1,2)* \sum_{LSV} \sum_{U,S} COML(U,S,LSV)$$

$$*INDLV(LSV) + \sum_{ZT=3}^{6} PTR(1,ZT)*AR(1,ZT)* \sum_{U,S,LS,LSV}$$

$$RESL(U,S,ZT,LS,LSV)*RESLV(S,LS,LV)$$

Part #2: Endogenous city income from buildings

$$ECIB = PTR(2,1)*AR(2,1)* \sum_{S,CGT,CPT,FACS} IS(S,CGT,CPT,FACS)*$$

$$ISV(S,CGT,CPT,FACS)+PTR(2,2)*AR(2,2)*$$

$$\sum_{S,CGT,CPT} CS(S,CGT,CPT)*CSV(S,CGT,CPT) +$$

$$\sum_{ZT=3}^{6} PTR(2,ZT)*AR(2,ZT)*$$

$$\sum_{S,HT,HV,HC} HS(T,S,HT,HV,HC)*HSV(S,HT,HV,HC)$$

ECIUF = some function of PST and PSE yet to be defined

$$ECI = ECIL + ECIB + ECIUF$$

$$PSI = ECI + \sum_{PST} [PTS(PST) + FTS(PST)]$$

Output

ECI

PSI

Module number 17

Local public service expenditures

Input variables

POP(T,OT,SL,AL,FS,SIEL,POR,POW)
POPCPS(AL,FS,AT)
PSA(T,PST)
PSD(S,PST)
PSL(T,S,PST)
WAGEH(T,OT,SL)

Model

Part #1: Calculate minimum level of public service attribute points for each sector.

$$PSMAP(S,AT) = \sum_{AL,FS} POPCPS(AL,FS,AT) * \sum_{OT,SL,SIEL,POW} POP(T,OT,SL,AL,FS,SIEL,S,POW)$$

Part #2: Public service labour demand

$$PSLABD(T,S,OT,SL) = \sum_{PST} PSLABR(PST,DT,SL) * PSL(T,S,PST)$$

Part #3: Maximize UFLPB(S,PST) (refer to submodel for complete specification of this function).

Subject to:

A. $PSTAC(PST,AT) * PSD(S,PST) \geq PSMAP(S,AT)$

where

$$PSD(T,S,PST) = \sum_{OT,SL,AL,FS} POPPSD(OT,SL,AL,FS,PST) * \sum_{SIEL,POW} POP(T,OT,SL,AL,FS,SIEL,S,POW)$$

B. $PSL(PST,S) \geq PSML(S,PST)$

C. $PSE(T,S,PST,PSST) = PSA(S,PST)$

In case of welfare PST = 3,

$$PSE(T,S,3,1) = WEL(S,WAGEH(OT,SL)* \sum_{AL,SIEL,FS} N(OT,AL,SL,SIEL,FS)$$

In case of criminal justice, PST = 1,

$$PSE(T,S,1,1) = \sum CRIME(OT,SL,AL,SIEL,FS,PSL)*COCR* POP(T,OT,SL,AL,FS,SIEL,POR,POW)$$

where

$$PSE(T,S,PST,PSST) = \sum_{OT,SL,PST,S} PSLABR(PST,OT,SL)* PSL(T,S,PST)*WAGEH(T,OT,SL) + \sum_{GT,PT,PST,IOE,S} PSMATR (PST,GT,PT,IEO)*PSL(T,S,PST)*IMATC(T,GT,PT,IEO)$$

Output

PSE(T,S,PST,PSST)
PSLABD(T,S,OT,SL)

For education PST = 2, the education level for each sector is also calculated

$$EL(T)=EL(T-1)+ED\ [(PSL(T,S,PST) \ -PSL(T-1,S,PST)),AL]$$

For welfare PST=3, the new income level is

$$WAGE(OT,SL) = WAGEH(OT,SL)+WEL(S,WAGE(OT,SL)$$

Module number 18

Transportation utilization

Input variables

(1) Amount of land in each physical sector allocated to transportation

TRANSL(S)

(2) Location of population and its place of work

POP(T,OT,SL,AL,FS,SIEL,POR,POW)

(3) Cost of transport as a function of both skill and income level.

COTR(WAGEH,OT,SL)

(4) Matrix giving intersectoral distances

$TRMA(S_1,S_2)$

(5) Matrix giving sectors crossed in transiting from one sector to another

$ISMI(S1,S2,SI) = R_1,R_2R_3,R_4$

Cost of transport to individual

$$CTI(T,OT,SL,AL,FS,SIEL) = F_1\ (UL(S)),\quad (TRMA(S_1,S_2))$$

Output

Cost of transport for each population sector

CTI(T,OT,SL,AL,FS,SIEL)

Transportation usage index

UL(S)

Module number 19

Land value determination

Inputs

LV(T,S,LS)
LPR(T)
HV(T-1,S,LS)
HPT(T-1,S,LS)

Model

$$LV(S,(S) = KLA \sum_{T=-1}^{-10} [(PR(T)*LV(T,S,LS)]$$

$$+ KLB[HV(T-1,S,LS)-HPT(T-1,S,LS)]$$

Where housing units were unoccupied in the previous period, HPT(T-1) = 0.

Output

LV(S,LS)

APPENDIX D:
MNEMONIC DICTIONARY

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
A	Acreage	VE	(ZT)	Acreage in sector S of land zoned as ZT	1,2,3	4
AL	Age Level	I	1-4	Indicates age category of head of household 1 - 20-30 years 2 - 30-50 years 3 - 50-65 years 4 - over 65 years		
AML	Attribute Minimum Level	M	(T,OT,SL,AL,AT)	Minimum required points of each attribute AT for a household OT, SL, and AL.	4	Tx360
AP	Attribute Points	VE	(AT)		4	5
AR	Assessment Rate	VX	(PRPT,ZT)		16	8
AT	Attribute Type	I	1-5	Indicates attribute 1 - Food 2 - Comfort 3 - Leisure 4 - Accessibility 5 - Environment		
B(S,M)	Exponent on Utility function of public representative	M	(S,M)	Lagged attribute levels	1	
CA	Commercial Acreage	M	(S)	Indicates total number of acres of commercial land in sector S.		12

Mnemonic	Name	Type	Range of values or dimensions of Matrix	Significance	Submodules in which it is used	Size
CCTW	Commuting Cost to Worker	M	(OT,AL,SL,S,POW)		4	
CF	Conversion Factor	VX		Used in IPRODG function	15	6912
CGT	Consumer Good Type (With reference to materials used in production)	I	1-5	To be indicated		
COCR	Cost of Crime	M		Public body expenditures per "unit" (incident, etc.) of crime	17	
COML	Commercial Land	M	(U,S)	Indicates number of acres zoned as commercial in each sector S which is currently being used U = 1 and not used U = 0.	3,16	120
COMLV	Commerical Land Value	M	(LSV)	Monetary value of commercial land/acre	16	5
CPG	Consumption of Goods	M	(OT,AL,SL,CGT,CPT)		4	1800
CPT	Consumer Product Type	I	1-5	To be indicated		
CRCI	Utility Function Coefficient	C		Coefficient in utility function for population	1	
CRIME	Crime Rate	M	(OT,SL,AL,FS,PSL)		16	

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
CS	Commerical Stock	M	(S,CGT,CPT)	Square feet in commercial buildings.	15	300
CST	Commercial Stock Type	I				
CSV	Commerical Stock	M	(S,CGT,CPT)	Market value per square foot in commercial buildings.	16	300
DEMG	Demand for consumer Goods	M	(T,CGT,CPT,OT,SL)	Demand of commodities by good and product type according to occupation and skill level.	8,10	TX450
EAG	Equitable Allotment of Goods	M	(CGT,CPT,OT,SL, AL)	Indicates relative buying power of different families in case of undersupply of consumer goods.	4	1800
ECI	Endogenous City Income	VE	(T)		15,16	T
ECIB	Endogenous City Income from Building	VE			16	
ECIL	Endogenous City Income from Land	VE			16	
ECIUF	Endogenous City Income from User Fees	VE			16	
ED	Education Function	F			17	
EL	Education Level	M	(T)		17	T

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
FACS	Factory Size	I	1-3	1 - Small 1 - Medium 3 - Large		
FS	Family Size	I	1-4	1 - 0-1 dependents 2 - 2-3 dependents 3 - 4-5 dependents 4 - 6 or more dependents		
FTS	Federal Tax Subsidy	VX	(PST)		15,16	5
GAM	Exponent in Industrial production	M	(CGT,CPT)		8,15	25
GT	Good Type consumed by industry in producing consumer goods	I	1-2	1 - durable 2 - nondurable		
GTAC	Good to Attribute Conversion	M	(OT,AL,SL,CGT, CPT,AT)	Assesses a certain number of attribute points to each good according to family type.	4	9000
HAC	Housing Attribute Conversion	M	(OT,AL,SL,FS, AT,HT)	Number of attribute points which a house HT contributes to a family	4	
HAL	Housing Allocation to Sectors	M			9	
HB	Housing Bid	F				

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
HC	Housing Condition	I	1-3	1 - Satisfactory 2 - Needs renovation 3 - Beyond feasible repair		
HE	Housing Expense	M	(OT,AL,SL,FS,HT)	Amount of money that a particular family would be willing to bid for housing.	4,7,9	
HEFI	Housing Expense Flexibility Indicator	M	(OT,AL,SL,FS)	Indicates the maximum acceptable increase of housing expense for family of certain type.	4,7,9	
HEP	Housing Prices	M	(S,HT,HC)		7	360
HINV	Vacant Housing	M	(S,HT,HC)		9	
HLABD	Labour Demand for Constructing Houses	M	(T,S,OT,SL)	Aggregate	9	TX216
HLABR	Labour Requirements for Housing Production	MF	(HT,HV,OT,SL)	Number of men of different OT and SL needed to construct different houses, per unit.	10	540
HLD	House-land-Distribution	M	(T,S,HT,HV,LS,LSV)	Number of houses by sector on various lot sizes.	9	TX10800
HLSV	Housing-Land Stock Value	M	(T,S,HT,HV,LS,LSV)	Value of housing on various lot sizes.	9	TX10800
HMATD	Material Demands for Housing	M	(T,S,GT,PT)		9	TX120

Mnemonic	Name	Type	Range of values or dimensions of matrix	Siynificance	Submodules in which it is used	Size
HMATR	Material Requirements for Housing production	M	(HT,HV,GT,PT)	Number of units of products needed to construct new houses, per unit.		300
HPROD	Production of Housing	M	(T,S,HT,HV)	Number of units in each class	7,10	Tx360
HPRODP	Cost of newly produced Housing	VE	(S,HT,HV)			360
HPT	Final Price of House and Lot	M	(S,HT,HC,LS)		7,19	
HS	Housing Stock	M	(T,S,HT,HV,HC)	Indicates number of house during period T in sector S of type HT, value HV and condition HC.	7,16	Tx1080
HSD	Housing Stock Demand	M	(T,S,HT,HV,HC)	Total demand for housing by type, value and condition for each sector.	4	Tx1080
HSP	Housing Producer's Offer Price	M	(S,HT,HC)		9	
HT	Housing Type	I	1-6	1 - Single family home for 1-3 occupants 2 - Single family home for 4-5 occupants 3 - Single family home for 6 or more occupants 4 - Small apartment building 5 - Medium apartment building 6 - Large apartment building (highrise)		

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
HV	Housing Value	I	1-5	One of five housing values for each type		
HVA	Offer Price of House and Lot	C	(S,HT,HC,LS)		7,9	
IA	Industrial Acreage	M	(S)	Total number of acres of industrial land in Sector S		12
ILABD	Industrial Labour Demand	M	(TS,OT,SL)	Aggregate	8,14	Tx216
ILABR	Industrial Labour Requirements	M	(T,CGT,CPT,OT,SL, FACS)	Number of workers of type OT and SL needed by factory of FACS per unit of CGT and CPT	8,10	Tx1350
IMATC	Material Cost for Industrial products	M	(T,GT,PT,IOE)	Cost of imported and endogenous materials used to make product of type GT and PT.	15,17	Tx20
IMATD	Material Demand for Industry to produce goods	M	(S,GT,PT,IOE)		8,15	240
IMATR	Industrial Material Requirements	M	(GT,PT,CGT,CPT, IOE,FACS)	Number of GT and PT imported or endogenous, needed per unit of CGT and CPT in factory size FACS	8	1500
INDCPS	Industry to Public Service conversion	M	(IT,IV,PST)	Number of units of PS needed by industry type and value.		125

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
INDL	Industrial Land	M	(U,S)	Indicates number of acres zoned as industrial in each sector S which is currently being used U = 1 and not used U = 0.	3,16	120
INDLU	Industrial Land Utili-zation	M	(S,U,GT,PT,FACS)	Amount of land in acres used by industry		720
INDLV	Industrial Land Value	M	(LSV)		16	5
IOE	Imported or Endogenous	I	1 or 2	Imported = 1 and Endogenous = 2.		
IPCF	Industrial Production Change Factor	VE		Percent increase or decrease of production		
IPRODG	Industrial Production	M	(T,CGT,CPT,FACS)	Number of goods of type CGT and CPT produced yearly in factories of size FACS	4,8,10,15	TX75
IPROF	Industrial Profit	M	(GT,PT)			10
IPS	Constant in Public Service utility function	C		Value yet to be assigned	1	
IS	Location of Industry Stock	M	(S,CGT,CPT,FACS)	Number of factories of size FACS located in sector S producing product of GT and PT type.	4,8,10,16	900

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
ISDI	Inter-sectorial Distance Information	M	(S1,S2)	Indicates number of sectors between S1 and S2.	18	144
ISMI	Inter-sectorial Movement Information	M	(S1,S2,SI)	Specifies the sectors indexed by SI between S1 and S2.	18	432
ISTC	Inter-sectorial Transportation Cost	M	(TOD,S1,S2)	Cost of going from sector S1 to S2 at certain time of day TOD.	4	432
ISV	Industrial Stock Value	M	(S,CGT,CPT,FACS)		16	900
IT	Industry Type	I	1-5	To be specified 1. 2. 3. 4. 5.		
ITR	Income Tax Rate	VX		Marginal Tax rate	4,6	5
ITX	Income Tax	VE	(OT,AL,SL)		4	48
ITXX	Income Tax Exponent Coefficient	C		Marginal tax rate adjusted for deduction.		
JRC	Binary Variable in Pollution Utility Function	VE	0 or 1	To cancel or include lag operators in UFPS	1	

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
JPS1	Binary Variable in ULPR	VE	0 or 1	To cancel or include lag operators in UFPS	1	
KA	Coefficient in AX Function	C	(AT,I)	I = 1 to 5	4	25
KHP1	Coefficient in HPROD equation	C			9	
KHP2	Coefficient in HPROD equation	C			9	
KIP1 KIP2	Coefficients in Consumer Product Production Function	C			8	
KIT	Coefficient in Income Tax Function	C		Deduction for dependents	6	
KKZ	Coefficient in KZ Function	C	(J,ZT,I)	I = 1 to 5	1,2	75
KL	House Producer's Markup	C			9	
KP	Pollution Constraint Variable	VX	(S)	Variable in utility function for regulatory constraint for population. Value yet to be determined	1	12
KPOP	Population Coefficient	C			1	

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
KPPG	Constant for Price per Consumer Good	C	(CGT,COT)	Coefficient	8,10	25
KRC1 KRC2 KRC3	Coefficients for KP Variable	C			1	
KRC4	Constant for KP Variable	C			1	
KWGH	Constant for Wage of Head of Household	C	(OT,SL)	Used in WAGEH function	10	20
KZ	Exponential Variable in UZ	VE	(J,ZT)	J = 1 to 3	1,2	15
LCIPG	Level of Consumption of Imported Private Goods	F	(OT,AL,SL,CGT, CPT)		4	1200
LCPG	Level of Consumption of Private Goods	M	(OT,AL,SL,CGT, CPT)		4	1800
LCPGF	Level of Consumption of Private Goods Function	F				
LCS	Level of Consumption of Private Services	M	(OT,AL,SL,ST)		4	360

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
LL					1	
LLP	Lower Land Percentage Limit	M	(S,ZT)	Indicates minimum proportion of sector zoned as ZT	2	60
LP	Level of Pollution	M	(S)	(Yet to be determined scale 1-10)	1	10
LS	Lot Size	I	1-6	1 - 0-¼ acres 2 - ¼-½ acres 3 - ½-1 acres 4 - 1-2 acres 5 - 2-3 acres 6 - over 3 acres		
LSV	Lot Size Value	I	1-5	(yet to be determined) 1 - 2 - 3 - 4 - 5 -		
LV	Lot Value	I	1-5	(yet to be determined) 1 - 2 - 3 - 4 - 5 -		
LV	Land Price	M	(T,S,LS)		9,20	

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
M	Major Good Category	I	1-4	1 = Consumer Products 2 = Consumer Goods 3 = Public Services 4 = Housing	1,4	
MI	Minimum Income	M			6	
MLC	Minimum Level of Consumption	M	(CGT, CPT, FS)			100
N	Number of Household by Type	VE	(OT,AL,SL,FS)		4,17	
OA	Other Land Use Acreage	M	(S)	Amount of acreage devoted to miscellaneous uses.		12
OT	Occupation Type	I	1-6	1 - Foreman, manager, administrator 2 - Salesman, cashier 3 - Teacher, nurse 4 - Professional like lawyer and doctor 5 - Factory worker 6 - Truck, gas, automobile driver or serviceman		
PAL	Public Attribute Level					
PC	Pollution Constraints	M		Yet to be defined		
PIPG	Price of Imported Private Goods		(T,CGT,CPT)			Tx10

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
POP	Population Statistics On Families	M	(T,OT,SL,AL,FS, POR,POW)	Number of families where head of household is	1,2,4,7,8,9, 10,17,18	Tx
POPCPS	Population Minimum Consumption of Public Service	M	(AL,FS,AT)		17	80
POPSD	Population Demand For Public Service Conversion Factor	M	(OT,SL,AL,FS, PST)	Conversion factor used to determine demand for public service according to household characteristics	17	960
POPTP	Population Transport Preference	M	(OT,SL,POR,POW)	Indicates use of private (=1) versus transport (=0)	18	3000
POR	Place of Residence	I	1-12	Indicates sector where family resides		
POW	Place of Work	I	1-12	Indicates sector where head of household works		
PPG	Price of Private Goods	M	(T,CGT,CPT)	Price of product CGT and COT in period T	4,8,10	Tx25
PPM	Price of Production Materials	M	(T,CGT,CPT)		8,9	Tx10
PPS	Price of Private Services	M	(T,ST)		4	Tx5

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
PPU	Price of Public Services	M	(S,PST)		4,5	60
PRPT	Property Type	I	1-2	1 - Land 2 - Building		
PSA	Public Service Allocation	M	(T,PST)		15,16	Tx5
PSAM	Exponent in PSL Function	M	(GT,PT)		15	25
PSC	Public Service Cost	M	(T,PST)	Cost of providing one unit of public service		Tx5
PSCF	Public Service Conversion Factor	VX		Used in PSL Function	15	
PSD	Demand for Public Service	M	(T,S,PST)		15,16,17	Tx60
PSDF	Public Service Differential					
PSE	Public Service Expenditure	M	(T,S,PST,PSST)		5,15,16	Tx60
PSI	Public Sector Income	VE			15	
PSL	Public Service Level	M	(T,S,PST)	Number of still undefined units of public service of type PST in sector S	1,4,5,10,16	Tx60
PSLABD	Public Service Labour Demand	M	(T,S,OT,SL)	Total demand for labour by public sector	15,16	Tx180

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
PSLABR	Public Service Sector Labour Requirements	M	(PST,OT,SL)	Number of OT's at SL's needed per unit of PS	10,15,17	90
PSMAP	Minimum number of Public Service Attribute Points	M	(S,AT)		15,17	Tx5
PSMATD	Public Service Material Demand	M	(T,S,GT,PT,IOE)	Total demand for materials by public sector	15	Tx240
PSMATR	Public Service Material Requirement	M	(PST,GT,PT,IOE)			100
PSML	Public Service Minimum Level	M	(S,PST)	Minimum level of PS calculated according to the residential, commercial and industrial components in a sector	: 17	60
PSST	Public Service Subtype	I	1 only			
PSS1	Public Service Series #1	M	(T,PST)	Lag operator - monotonically decreasing	1	Tx5
PSS2	Public Service Series #2	M	(T,PST)	Lag operator - monotonically decreasing		Tx5
PST	Public Service Type	I	1-5	1 - Criminal justice, protection 2 - Education 3 - Welfare and Unemployment 4 - Mass transit 5 - Water and sewerage, solid waste, other		

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
PSTAC	Public Service To Attribute Conversion Matrix	M	(OT,AL,SL,PST, AT)	Contains number of attribute points per unit of PS	4,15,17	
PSX	Exponent in PSL Function	VE	(OT,SL)		15	20
PT	Product Type consumed by industry to produce consumer goods	I	1-5	(yet to be determined) 1 - 2 - 3 - 4 - 5 -		
PTR	Property Tax Rate	VX	(PRPT,ZT)		16	10
PTS	State Tax Subsidy	VX	(PST)		15,16	5
PUBSEL	Public Sector Extensive Land utilization	M	(S)	For example, parks	3	12
PUBSIL	Public Sector Intensive Land utilization	M	(S)	Number of acres used for public buildings	3	12
R	Public Sector Revenues			Public Sector budget constraint	4,5	
RA	Residential Acreage	M	(S)	Total number of acres of residential land in Sector S		12

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
RCT	Regulatory Constraint Type	I	1-3	(yet to be defined) 1 - 2 - 3 -		
RCX	Regulatory Constraint Exponent	M	(RCT)	Used in UFRCP	1	3
RESL	Residential Land Data	M	(U,S,ZT,LS,LSV)	Number of lots zoned as residential of size LS and value LSV in sector S which are currently being used U = 1 and which are vacant U = 0	3,9,16	2880
RESLV	Residential Lot Value	M	(S,LS,LSV)	Value of Residential lot of Size LS in sector S	9,15	360
S	Sector	I	1-12			
SI	Sector Index	I	1-3			
SIEL	Second Income Earner Level	I	1-3	(yet to be defined) 1 - 2 - 3 -		
SKZ	Coefficient in UZ Function	C	(ZT)	Scaling coefficient 0 SKZ 10	1,2	5
SL	Skill Level	I	1-3	(yet to be defined) 1 - 2 - 3 -		

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
ST	Private Service Type	I	1-5	(private services yet to be determined) 1 - 2 - 3 - 4 - 5 -		
STAC	Private Service to Attribute Conversion	M	(OT,AL,SL,ST, AT)		4	1800
T	Time Period	I				
TA	Total Acreage	M	(S)		1,2,3	12
TDEMG	Total Demand for Consumer Goods	M	(T,CGT,CPT)		8,10	Tx25
TIA	Total Industrial Acreage	VX		Limit		
TLABD	Total Labor Demand	M	(T,S,OT,SL)		10	Tx216
TLABS	Total Labor Supply	VE	(T,S,OT,SL)		10	Tx216
TM	Means of Transportation	I	0-1	0 - Public transport 1 - Private car		
TOD	Time of Day	I	1-3	1 - Morning 2 - Evening 3 - Non-rush hour time		

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
TPRODG	Total Production of Goods	M	(T,CGT,CPT)		8	Tx25
TRAF	Traffic	M	(S,TOD)		18	36
TRMA	Intersectoral Distances	M	(S1,S2)		18	144
TRNSC	Transportation Cost	M	(S1,S2)		18	144
TRNSL	Transportation Network Land Usage	M	(S)	Number of acres of land zoned for transportation networks	3,18	12
TSCG	Total Supply of Goods	V	(T,CGT,CPT)		4,8,10	Tx25
TUZ	Total Utility for Zoning	M	(S)			12
TVUP	Total Value of Urban Property	VE			4	Tx25
TZA	Total Acreage in city zoned as ZT	M	(ZT)		1,2	5
T1	Time Limit #1	VX		Limit over past time of influence of public service levels on aspirations		
T2	Time Limit #2	VX		Limit over past time of influence of public service levels on expectations		

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
U	Utilization of land for intended purpose	I	1-2	1 - land used as intended 0 - vacant		
UCZ	Utility for Commercial Zoning					
UZ	Utility for Zoning	F	(S,ZT)		1,2	60
UF	User Fees for public services	M	(PST,PSE)			20
UFA	Utility Function for Attributes	F	(AT)		4	5
UFLPB	Utility Function value for Local Public Body	M	(S)		1	12
UFPST	Utility Function for Total Public Service	M	(S)	Value of utility functions for public services	1	12
UFRCP	Utility Function for Regulatory Constraints - Pollution	F			1	
UFRCZ	Utility Function for Regulatory Constraints - Zoning	F	(S)		1	

Mnemonic	Name	Type	Range of values or dimensions of matrix	Significance	Submodules in which it is used	Size
ULET	Utility for leisure	F			19	
UL	Transportation Usage Index	VE	(S)		18	
ULP	Upper Land Percentage	M	(S,ZT)	Indicates maximum proportion of sector zoned as ZT	2	60
ULRN	Usage Level of Road Network	VE	(S,TOD)		18	36
UTWO	Utility for Work	F				
UUZ	Utility for Un-used land	F				
WAGE	Total income of household	F	(OT,AL,SL)		4,6,19	
WAGEH	Wage of Head of household	M	(T,OT,SL)		8,9,10,15 17	Tx18
WEL	Welfare Supple-ment	M	(S,WAGEH (OT,SL))		17	144
WTD	Work Transporta-tion Differential	M	(S1,S2)	S1 - new sector residential location S2 - old sector residential location	7	144
ZT	Zoning Type	I	1-5	1 - Commercial 2 - Industrial 3 - Residential A 4 - Residnetial B 5 - Other		

APPENDIX E:

DATA SOURCES FOR MODEL VARIABLES

DATA SOURCES FOR MODEL VARIABLES

Mnemonic	Name	Primary Data Source	Auxiliary Data Source
A	Acreage Zoned	Regional Planning Agency (RPA)	City, town, county zoning maps
AL	Age Level	U.S. Census Bureau Fourth Count Tapes	Annual city and town level Censuses of Households
AR	Assessment Ratio	State School Aid Equalization Agency	Individual city, town and county reports
CA	Commercial Acreage	RPA	Individual city, town and county level use studies and plans
CCTW	Commuter Cost to Worker	Peak Hour Travel Cost (time) Tables (District Level) from RPA or Metropolitan (Transportation) Planning Organization (MPO)	Average trip length data from The Journey to Work, Special Studies P-23, No. 99 of Current Population Reports, U.S. Census Bureau
COCR	Cost of Crime No. and type of Crime Public Safety Expenditures	State Attorney General State Departments of Community Affairs	1973 U.S. Census Bureau Study of National Crime Rates 1977 Census of Governments, Table 22
COML	Commercial Land Used	Calculated from data collected for Variables 1 and 4	
COMLV	Commercial Land Value	State assessment equalization agencies	City, town and county assessments
CRIME	Crime Rate	State Attorney General's Office	1973 U.S. Census Bureau Study of National Crime Rates
CS	Commercial Square Footage	Regionwide Real Estate Inventories (e.g., Ryan-Elliot Survey in Boston Area)	Sanborn or similar city by city maps

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Source
CSV	Commercial Buildings Value	Regionwide Real Estate Inventories	Property assessment records factored by assessment ratios
DEMA	Demand for Consumer Goods	U.S. Department of Labor consumer expenditures studies by SMSA and by income. Income must be correlated with occupation from data in the U.S. Census Public Use Sample.	
ECI	Endogenous Regional Municipal Income	Table 22 of the U.S. Census of Governments, Finances of Municipalities and Township Governments, Vol. 4.	Individual city, town and county annual reports
ECIB	Endogenous Regional Municipal Income from Buildings	Estimates from city, town and county assessor's records	Taxpayer's Research Groups
ECIL	Endogenous Regional Municipal Income from Land	Estimates from city, town and county assessor's records	Taxpayer's Research Groups
ECIUF	Endogenous Regional Municipal Income from Users Fees	Table 22 of the U.S. Census of Governments, Finances of Municipalities and Township Governments, Vol. 4 (Also Tables 16 & 17)	Individual city, town and county annual reports
FTS	Federal (and State) Tax Subsidy	Intergovernmental Transfers to Local Government reported in Table 22 of the U.S. Census of Governments, Finance of Municipalities and Township Governments	
HEP	Housing Prices	Tables A-2, B-2, and C-2 Annual Housing Survey, U.S. Census Bureau and U.S. Department of Housing and Urban Development	Decennial Census of Housing (SMSA: Tables 10 and 15) (Tract Level: Table H-2)

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Sources	Auxiliary Data Sources
HINV	Vacant Housing	Current Housing Reports Housing Vacancies Series H-111 (Quarterly), Tables 4-9, U.S. Census Bureau	U.S. Department of Housing and Urban Development postal based vacancy survey
HLABD	Labor Demand for Construction of Housing	C-Series of Current Housing Report, U.S. Census Bureau Housing Construction Components Cost	
HLABR	Labor requirements for housing population	C-Series of Current Housing Report, U.S. Census Bureau Housing Construction Components Cost	
HLD	House-land-distribution	RPA and special residential density studies	
HLDV	Housing Land Stock Value	Price Index of New One-Family Houses Sold, Construction Reports C-27 Series (Lot size included since 1974)	Special surveys of local real estate data
HMATD	Material Demands for Housing	C-Series of Current Housing Report, U.S. Census Bureau Housing Construction Components Cost	
HMATR	Material Requirements for Housing Production	<u>Construction Review</u> U.S. Department of Commerce	National Association of Homebuilders and NAHB Research Fund
HPROD	Production of Housing	C-20, C-21, C-22, and C-40 Series by the U.S. Bureau of Census. C-40, viz. <u>Housing Units Authorized by Building Permit and Public Contract</u>, is monthly at U.S. level and annual at county level.	

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
		C-20, viz. New Residential Construction in Selected SMSAs (permits, starts, and completions) is quarterly. C-20, viz. Housing Starts, is monthly at U.S. level and census divisions, as is C-22, viz. Housing Completions	
HPT	Final Price of House and Lot	C-27, viz. Price Index of New One-Family Houses Sold, provides indices controlled for quality and for actual houses sold. It is quarterly for U.S. and annual for Census divisions. To translate from U.S. level or Census-division level to regional level, compare values of recently-built owner-occupied units (e.g., post-1970) for different levels of geography as given in Annual Housing Survey, Part C, Tables A-2, B-2 and C-2. This also provides sub-regional data for each SMSA, namely central city vs. balance.	
HPRODP	Cost of Producing New Housing	Construction Review, U.S. Department of Commerce, and BLS Bulletins 1755, 1892, and 1821 for SIC detail.	
HS	Housing Stock	Annual Housing Survey, U.S. Bureau of Census. Voluminous tables relating stock by type, condition, and value to occupants by characteristics.	
HSD	Housing Stock Demand (Households)	Same as HS	

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
IMATD	Material Demand for Industry to Produce Goods	Tables 2 and 3 of the 1977 U.S. Census of Manufactures (State and detailed national level data must be factored to each metropolitan area based on regional industrial composition and size.)	
IMATR	Industrial Material Requirements	IMATD divided by unit of average consumer durable and non-durable goods, sorted by factory size categories. Same data source as above (IMATD) variable.	
INDCPS	Industry to Public Service Conversion	Various EDA and EPA studies of urban infrastructure and public service requirements of various industries.	
INDL	Industrial Land	RPA	Local and state government land use studies
INDLU	Industrial Land Utilization	RPA	Local and state government land use studies
IA	Industrial Acreage	RPA land use inventories and studies	Special surveys of industry done by State Commerce Departments and Private Industrial Councils
ILABD	Industrial Labor Demand	State Department of Employment Security (DES) Employed workers by SIC code	Industrial Directories showing employment size class, compiled by Chambers of Commerce, etc.
ILABR	Industrial Labor Requirements	Industry-occupation matrix prepared by most State Departments of Employment Security (For example, *Massachusetts Occupational Profile*)	National Industry-Occupation Matrix updated to 1978 by the U.S. Department of Labor
IMATC	Material Cost for Industrial Products	Tables 2 and 4 of the 1977 U.S. Census of Manufactures. (State and detailed national level data must be factored to each metropolitan area based on industrial composition of the area.)	

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Sources	Auxiliary Data Sources
INDLV	Industrial Land Value	Directories and advertisements of industrial realtors	State Department of Commerce Industrial Land Files
IPRODG	Industrial Production	Tables 2 and 3 of the 1977 U.S. Census of Manufactures (State and detailed national level data must be factored to each metropolitan area based on regional industrial composition and distribution of establishment size.)	
IS	Location of Industry Stock	RPA or MPO	Industrial Directories prepared by Chambers of Commerce, etc.
ISDI	Intersectorial Distance Information	MPO Highway Networks	State Department of Transportation
ISMI	Intersectorial Movement Information	MPO Highway Networks	State Department of Transportation
ISTC	Intersectorial Transportation Cost	MPO	State Department of Transportation
ISV	Industrial Stock Value	Table 2 of the 1977 U.S. Census of Manufactures (State data must be factored to metropolitan area data and new plant and equipment data must be expanded to all existing plant and equipment).	
ITR	Income Tax Rates	State Department of Corporations and Taxation; U.S. Internal Revenue Service	Taxpayers' Foundation
ITX	Income Tax	State Department of Corporations and Taxation; U.S. Internal Revenue Service	
LLP	Lower Land Percentage Limit	RPA	

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
LP	Level of Pollution	Regional EPA Office	
LV	Land Prices	Advance Mortgage Corporation (Chicago)	Local Real Estate Board, Homebuilders' Association
N	Number of households by type	P.U.S.*	Fourth count summary tapes by tract
OA	Other Land Use Acreage	RPA	City and town planners
POP	Population Statistics of Families	P.U.S.*	Fourth count summary tapes by tract
POPTP	Population Transport Preference	P.U.S.*	Fourth count summary tapes by tract
PPG	Price of Private Goods	Bureau of Labor Statistics of U.S. Department of Labor computes cost of goods and services for "market baskets" by SMSA by level	Finer product detail available at national level; e.g., from _Survey of Current Business_

*P.U.S. = Public Use Samples from the U.S. Census Bureau. This is the only source for variables having complex subscript combinations (e.g., age, occupation, skill level, and family size). Rough approximations could be obtained from two-way and three-way cross-tabulations in the fourth count summary types, which is listed as an auxiliary source.

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
PPS	Price of Private Services	Bureau of Labor Statistics of U.S. Department of Labor computes cost of goods and services for "market baskets" by SMSA by income level	Finer product detail available at national level; e.g., Survey of Current Business
PPU	Price of Public Sector Services	Census of Governments, Government Finances, IV, #4	
PSC	Public Service Cost	Same as PPU	Same as PPU
PSD	Demand for Public Service	Same as PPU	Same as PPU
PSE	Public Service Experience	Same as PPU	Same as PPU
PSI	Public Service Income	Same as PPU	Same as PPU
PSL	Public Service Level	Same as PPU	Same as PPU
PSLABD	Public Service Labor Demand	Census of Governments, Public Employees, III.	Public Employment in (year), series GE (annual)
PSLABR	Public Service Sector Labor Requirements	Same as PSLABD	Same as PPU
PTR (cf AR)	Property Tax Rate	State School-Aid Equalization office	Taxpayers' Foundation, Homebuyers' Guide, Regional Atlas
PTS	State Subsidy Tax	State budget document	
PUBSEL	Public Sector Extensive Land Utilization	RPA	City and town planners

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
PUBSIL	Public Sector Intensive Land Utilization	RPA	City and town planners
R	Public Sector Revenues	*Census of Governments: Governmental Finances*, IV, #4, U.S. Bureau of Census	City Budget Official
RA	Residential Acreage	RPA	City and town planners
RESL	Residential Land Value	Advance Mortgage Corporation, Chicago	Local Real Estate Board or Homebuilder's Association
RESLV	Residential Lot Value	Advance Mortgage Corporation, Chicago	Local Real Estate Board or Homebuilder's Association
TA	Total Acreage	RPA	
TDEMG	Total Demand for Consumer Goods	Bureau of Labor Statistics of U.S. Department of Labor	
TLABD	Total Labor Demand	State DES	
TLABS	Total Labor Supply	State DES	
TPRODG	Total Production of Goods	State Department of Commerce	Major university may have economic research center
TRAF	Traffic	MPO as designated by law	State Department of Transportation or Department of Public Works
TRMA	Intersectoral Distances	MPO as designated by law	State Department of Transportation or Department of Public Works

DATA SOURCES FOR MODEL VARIABLES (continued)

Mnemonic	Name	Primary Data Source	Auxiliary Data Sources
TRNSC	Transportation Cost	MPO as designated by law	State Department of Transportation or Department of Public Works
TRNSL	Transportation Network Land Usage	Same as TRNSC	Same as TRNSC
TSCG	Total Supply of Goods	Same as TPROG	
TVUP	Total Value of Urban Property	State Department of Revenue or Tax Equalization	
TZA	Total Acreage in Region Zoned as ZT	RPA	
UF	User Fees for Public Services	*Census of Government: Government Finances*, IV, #4, Tables 16 & 17	
UL	Transportation Usage Index	MPO and Public Transit Authority	Same as TRNSC
ULRN	Usage Level or Road Network	MPO	Same as TRNSC
WAGE	Total Income of Household	P.U.S. (Public Use Sample)	
WAGEH	Wage of Head of Household	P.U.S. (Public Use Sample)	
WEL	Welfare Supplement	P.U.S. (Public Use Sample)	State Dept. of Public Welfare
WTD	Work Transportation Differential	Same as CCTW	

APPENDIX F:

BIBLIOGRAPHIC REFERENCES FOR KEY MODEL VARIABLES

BIBLIOGRAPHIC REFERENCES FOR KEY MODEL VARIABLES

1. EAG. Equitable distribution of consumer goods in case of undersupply.

   (a) Howard, D. H. "Rationing, Quantity Constraints and Consumption Theory," Econometrica, March 1977, 45(2), pp. 399-412.

   This paper presents a general proof of a fundamental proposition of rationing theory and demonstrates that it applies to some basic potulates of micro-economic theory, including the consumption faction.

2. HAC. Housing preferences by household type.

   (a) Baxter, R. "A Model of Housing Preferences," Urban Studies, June 1975, 12(2), pp. 135-149.

   This paper adapts a residential location model in order to generate indices for housing attractiveness amongst groups in the population. Values for these indices are examined against housing characteristics of space and location in order to suggest significant causative factors.

   (b) Brueckner, J. "The Determinants of Residential Succession," J. Urban Economics, 1977, pp. 45-59.

   This study attempts to measure residential succession or the succession of neighborhoods from high-to-low-income occupancy, and to relate its occurrence to explanatory variables suggested by various theories.

   (c) Ball, M. J. and Kirwan, R. M. "Accessibility and Supply Constraints in the Urban Housing Market," Urban Studies, 1977, pp. 11-32.

   This paper discusses some of the chief influences on the urban housing market and their significance for economic analysis. Although spatial clusters of households and housing types clearly emerged, the empirical tests showed that such spatial structures did not produce separate sub-markets with independent price structures.

(d) King, A. T. "The Demand for Housing: A Lancastrian Approach," Southern Economic Journal, 1976, 43(2), pp. 1077-1087.

In this paper housing is treated as a bundle of distinctly different commodies and the demand for these is examined. The various components are found to respond quite differently to change in incomes, prices, family size, and expectations.

3. HEFI. Housing market microbehavior; offer vs. transaction, prices vs. consumer budget for different household types.

(a) Chinloy, P. T. "Hedonic Price and Depreciation Indexes for Residential Housing: A Longitudinal Approach," J. of Urban Economics, 1977, pp. 469-482.

An equilibrium price relation is derived for price changes in durable goods capable of generating a hedonic, or quality-corrected, price index, and an index of depreciation. The structure proposed is applicable particularly to housing markets, where longitudional or repeat-sale data are readily available from assessment or real estate sources.

(b) Davis, G. W. "A Model of the Urban Residential Land and Housing Markets," Can. Journal of Economics, 1977, pp. 393-410.

A monthly dynamic model of the urban residential land and housing markets is estimated. A one-time exogenous increase in the number of vacant, single-family detached lots is shown to have a reasonably large effect on lot prices, but much smaller effects on the other variables in the model.

(c) Maclennan, D. "Some Thoughts on Nature and Purposes of House Price Studies," Urban Studies, 1977, pp. 59-71.

This paper examines the implicit assumptions made in hedonic studies of urban house prices. The study suggests that the methodology adapted in previous studies for testing hypotheses about residential models are inappropriate and possible avenues of development for house price research are outlined.

(d) Witte, A. D. "The Determination of Inter-urban Residential Site Pricing Differences: A Derived Demand Model with Empirical Testing," J. of Regional Science, 1975, 15(3), pp. 351-364.

A derived demand model of residential site price determination is developed. According to this model, differences in the price of residential sites among urban areas are the result of differences in the demand for housing, differences in supply of other inputs, and differences in supply of sites.

4. JRC. Lag structure on pollution control demand models on formation of expectation; persistence of aspirations as function of achievement of expectations (adaptive expectation models, etc.).

5. JPSI. Same, for public services.

   (a) Nelson, C. R. "Rational Expectations and the Predictive Efficiency of Economic Models," Journal of Business, 1975, 48(3), pp. 331-343.

   This paper suggests that under more general circumstances a rational expectation cannot be reduced to a univariate extrapolation and can be shown to be more efficient in a general expected utility sense than the optimal extrapolative predictor.

   (b) Pesando, J. E. "Rational Expectations and Distributed Lag Expectations Proxies," J. American Statistical Association, 1976, 71(353), pp. 36-42.

   This paper reviews the properties of rational expectations in the context of auto regressive forecasting. It also provides insights into the usefulness of rationality as a criterion for both evaluating and constructing distributed lag expectations proxies.

6. KHP1. Elasticity of housing production (units) with respect to differential between offer and transaction prices.

7. KHP2. Same, with respect to change in inventory of vacant units.

   (a) Lee, T. H. and Kong, C. M. "Elasticities of Housing Demand," Southern Eco. Journal, 1977, pp. 298-305.

   The low estimates of the income elasticity of housing demand obtained when individual households are the unit observation are theoretically reconciled with high estimates obtained when metropolitan-wide averages are used. The price elasticity is biased upward.

8. KIP1. Elasticity of production of consumer goods with respect to price change in previous period.

9. KIP2. Same, with respect to quantity of imported goods.

(a) Fisch, O. "Dynamics of the Housing Market," J. of Urban Economics, 1977, pp. 428-447.

This paper deals with the derivation of the rent values of the standing stock of the housing market with a continuous vintage approach, under mall eagle stock and homogeneous population assumptions, and under dynamic conditions, population and income growth, technological obsolesence, and a continuous upward shift and elasticity change in the supply function.

(b) Morris, D. "Household Production Theory, the Lancaster Hypothesis and the Price-Quality Relationship," Bull. of Economic Research, 1978, pp. 14-24.

The hedonic principle assumes that there exists a consistent relationship between the prices and quality of different varies of product. The Lancasterian version of microeconomic theory has been applied to identify the relationship. A specific price-quality model is developed and is applied to the U.K. passenger car market.

(c) Van Alphen, H. J. and Merkies, A. H. "Distributed Lags in Construction: An Empirical Study," Int. Eco. Review, 1976, pp. 411-430.

Using a disaggregation of quarterly production data over projects with equal starting period, a direct estimate is obtained for the distributed lag function for the construction of houses in the Netherlands.

10. KKZ. Preference for zoning by household characteristics.

(a) Hamilton, B. W. "Zoning and the Exercise of Monopoly Power," J. of Urban Economics, 1978, pp. 116-130.

No economic agents, as it appears, have control over the price of housing in any location; yet with the institution of zoning it is possible to restrict supply of housing by monopolistic practices. In this paper, it has been agrued that, through the use of zoning and other land use restrictions, such monopolistic supply restriction is widespread.

11. KL. House producers' mark-up.

(a) Stull, W. J. "Selling Land to the Highest Bidder: An Application of the Beauty Contest Problem," J. of Regional Science, 1978, pp. 411-427.

Constructs a model of the land sale process which takes into account market sequentation and non-simultaneity of offers. Information available to the landowner is first specified. A theory of land selling under uncertainty is then developed, based upon the well-known beauty contest problem.

12. KP. Utility of pollution control by household characteristics.

(a) Rothenberg, J. "The Economics of Congestion and Pollution: An Integrated View," American Economic Review, Papers & Proceedings, May 1970, pp. 114-121.

The author develops a model in which congestion and pollution problems are treated as a single class. The distribution of effects of externalities on different segments of the population and the costs and values of treatment are derived analytically and examined with respect to population and income growth.

(b) Kneese, A. V. "Rationalizing Decisions in the Quality Management of Waters -- Supply in Urban/ Industrial Areas".

Describes the character of pollution-imposed externalities from a theoretical perspective, and indicates ways of handling difficult-to-evaluate water uses, such as recreation.

13. KPOP. Weighting on sector population.

(a) Rothenberg, J. "Local Decentralization and the Theory of Optimal Government" in J. Margolis (ed.), The Analysis of Public Output.

The paper is concerned with the welfare evaluation of local government in the typical metropolitan area. Among other topics, it deals with the fragmentation of local government in the metropolitan area into various nonhierarchical jurisdictions. It suggests how reduced cost of service provision due to scale economies might be used to overcome the adverse redistributiive effects of externalities.

(b) Bradford, D. F. and Oates, W. "Suburban Exploitation of Central Cities and Governmental Structure in Hochman, H. and G. Peterson, Redistribution through Public Choice.

14. KPPG. Inverse price elasticity of demand for consumer goods.

(a) Maccini, L. J. "The Impact of Demand and Price Expectations on Behavior of Prices," AER, 1978, pp. 134-145.

This paper conducts an analysis of the effects of demand and price expectations on the behavior of prices. A model of price behavior is proposed, and the model is tested with data from the manufacturing sector of the U.S. economy.

(b) The papers already cited under Items 4. and 5.

15. KWGH. Wage elasticity with respect to demand by occupation.

(a) Kelley, K. C. "Urban Disamenities and the Measure of Economic Welfare," J. Urban Eco., 1977, pp. 379-388.

A labor market model is used to estimate elasticity between various disamenity factors of urban areas and wage in these areas. The results are used to calculate personal income data for the use in the construction of an index to be used as a measure of economic welfare.

(b) Azevido, R. B. "Scientists, Engineers and the Reservation Wage," Quart. Rev. of Eco. and Business, 1977, pp. 41-51.

This article reports an empirical investigation of the behavior of the reservation wage among scientists and engineers. The results demonstrate that the behavior of the reservation wage is far from uniform, but rather functionally related to the level of unemployment and conditions surrounding the job change.

(c) Gottschalk, P. T. "A Comparison of Marginal Productivity and Earnings by Occupation," Industrial and Labor Relations Review, 1978, pp. 368-378.

This paper estimates the marginal productivity of eight different occupations by estimating production models with cross-section data and comparing the estimated marginal products with factor payments. It appears that blue-collar occupations are paid less than they produce, while capital and white-collar occupations are paid more than they produce.

(d) Izraeli, O. "Differentials in Nominal Wages and Prices between Cities," Urban Study, 1977, pp. 275-290.

It is well-known that great variations in money wages and prices can exist within a country even when these differentials are widely known and there is no legal barrier to mobility. This article investigates the possibility that the differential availability or quality of environmental goods may be an explanatory variable. The analysis suggests that people are sensitive enough to the availability of environmental goods for this to explain most of the observed variations in wage rates and the price index.

16. PC. Cost of pollution control.

(a) Small, K. A. "Estimating the Air Pollution Costs of Transportation Modes," J. Transportation Eco. Policy, 1977, pp. 109-132.

Recent literature on aggregate costs of U.S. air pollution to health, materials and agriculture is reviewed and adopted so as to provide lower bound estimates of the average damages attributable to a unit emission in a U.S. urban area. The cost estimates range from 0.04 to 0.36 cents per mile for various cars in an average U.S. metropolitan area.

(b) Smith, V. K. and Deyak. T. A. "Measuring Impact of Air Pollution on Property Values," J. Regional Science, 1975, pp. 277-288.

This paper extends the general residential location model to include local public services, taxes, and air pollution as determinants of property values. In both the owner and renter markets, the air pollution variable was found not to be a statistically significant determinant of property values or rents.

17. POPCPS. Minimum consumption of public services by population type.

    (a) Legvand, J. "The Distribution of Public Expenditure: The Case of Health Care," Economica, 1978, pp. 125-142.

    This paper attempts to estimate the distribution of public expenditures on health care between different social groups in Britain. The results are tentative, but suggest that, relative to mobility, National Health Service expenditures is distributed unequally, with higher socioeconomic groups receiving up to 40 percent more expenditure per person reporting illness than the lower groups.

    (b) Wright, C. "Financing Public Goods and Residential Location," Urban Study, 1977, pp. 41-50.

    The article introduces public goods into a residential land-use model and examines the location consequences of alternative methods of financing such public goods. The effects on rents and density are shown to differ according to whether the public goods are financed by benefit taxes, income taxes, property taxes or land value taxes.

    (c) Adams, Robert F. "On the Variation in the Consumption of Public Services," Rev. Eco. & Stat., 1965, pp. 400-405.

    In a multivariate analysis, variations in demand for public services, as measured by per capita expenditures is examined as a function of variables related to socioeconomic environment, physical environment, income and wealth, individual characteristics and political or institutional factors.

18. POPPSD. Public service demand by population type.

19. PSML. Minimum level of public services provided by sector.

20. PSTAC. Public services attributes.

    (a) Gustely, R. D. "Public Service Pricing and Urban Housing Demand: An Analysis of Land Use Impact," Southern Eco. Journal, 1978, pp. 75-89.

This paper analyzes the long-run housing market impact of shifting to a user charge system of financing urban public services. The results indicate that the employment of these charges would have a beneficial long-run effect on the pattern of residential development and that in certain fringe area developments, the effects could be substantial.

21. STAC. Private goods attributes.

(a) King, A. T. (See under Item 2.)

APPENDIX G:

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APPENDIX H

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. Multi-sectoral urban economic simulation, market optimization and heuristic devices were introduced as concepts for analyzing the implications of various theories related to the spatial arrangement of activities within urban areas under a wide range of conditions in the urban economy.

Societal Linkages Model

A Proposal Submitted to the
U.S. Department of Transportation
Transportation Systems Center

April 9, 1980

Societal Systems Analysis: An Alternative Approach to Transportation Policy and Planning Modelling

The Urban Systems Laboratory
University of Illinois at Chicago Circle
College of Engineering
Chicago, Illinois 60680

TABLE OF CONTENTS

*Section not included

I. Societal Systems Approach to Transportation Planning Methodology

The purpose of the research program that is proposed in this report is to develop a transportation policy and planning methodology that utilizes the functional role of accessibility as the basis for establishing transport requirements. "Functional role" is defined as the linkage between the consumer and the output of the production system (access), as well as the freight and person movement that is needed to produce the output (production). A unique property of this approach is to employ a quality of life criterion as a basis for analyzing the effects of transportation and determining the requirements for transportation. The proposed model structure is an abstract modal approach designed ultimately as a policy and planning tool. It is conceived as a strategic model rather than a tactical one of which UTPS is an example.

The underlying concept involves two considerations. One is the disaggregation social organization into a set of societal systems which represent the sources of goods and services from which the population can obtain satisfaction of essential as well as discretionary needs. Two is the effectiveness of these institutional arrangements as measured by the consumers' ability to obtain the specific goods and services that define their actual quality of life.

Thus, one basic element of the proposed approach is the taxonomy of consumer needs and desires, which is the underlying determinant of the output of the production system. It is our view that the societal systems are definable by the way in which consumers dispose of their resources and in the way in which government provides direct support for services. Consequently, one can look at two basic economic measures to identify these societal systems. One is the Personal Consumption Expenditure and the other is Government Purchase of Goods and Services. As has been noted (Baker et al, 1978), there are ten such societal systems involving expenditures that account for 2/3 of the GNP. These systems can be classified into three groups, and are shown in Table 1. It should be noted that each of these systems is presumed to provide an element necessary to or desired by members of a society to insure their security, safety and satisfaction. It is how well these systems satisfy needs that determine what is called the quality of life.

Although the concept "quality of life" has been used for the past 20 years in a descriptive sense, it has received considerable attention in the social and behavioral sciences as a basis for social accounting (United Nations Report, 1954; McGranahan, 1971; Milbrath, 1979). The term has been developed, as a construct, from both a global "consumer" standpoint and a societal system standpoint. The first has been concerned with individuals' overall satisfaction with the elements of their lives. Several cross-cultural studies suggest that individual's evaluation of "quality of life" is a relative measure of their outlook on life (Galnoor, 1971; Guttman, 1971; Milbrath, 1979)and in this sense

Table 1
Societal Systems for Providing
Quality of Life Goods & Services

A. Life Support

1. Food
2. Clothing
3. Shelter
4. Health Care

B. Protection

1. Public Safety

   a. Fire
   b. Police
   c. Natural Disaster-Civil Defense

2. National Defense

C. Enrichment

1. Education

2. Culture
   a) Arts
   b) Music
   c) Theater

3. Religion

4. Recreation

is a useful measure of short-term trends. However, because subjective satisfaction is relative, it does not appear highly correlated with the quality and quantity of goods and services available to consumers. (Milbrath, 1979).

The second use of the term quality of life refers specifically to the performance of each of the societal systems. This is essentially the approach taken by OMB in the compilation of the Biennial Social Indicator Report. The performance of each system can be evalutated in relation to its own objective function. For example, the health care system is intended to reduce the incidence and duration of disease processes and to increase the longevity of the population. By comparing life span over time or in different societies or by measuring the changes in the frequency and duration of hospital confinements, it is possible to quantitatively estimate the effectiveness of the health care system. Indeed, in theory, if each of the ten societal systems is analyzed, it should be possible to measure its effectiveness in providing its goods and services across the population. What is required is: 1) to define its objectives in terms of its services; 2) to specify the means by which it is organized to provide goods and services; 3) to evaluate the effectiveness of these means in achieving its objectives. Thus it should be possible to determine for each system the quality of life it provides given its present structure. This performance measure can be defined in absolute or relative terms. For example, the objective of a fire protection system may be stated as prevention of the absolute loss sustained by fires given the state-of-the-art

technology for fire protection and control. The quality of life can also be defined in relative terms: How well a societal system can achieve a specific goal.

If such objective functions can be defined, then a system-specific quality of life metric may be derived: $Q.L._i$. Of the ten quality of life systems, at least five have objective functions that can be so defined. These are food, shelter, clothing, health care and public safety which account for 73% of the total expenditure for personal goods and services. It should be noted, however, that given a $Q.L._i$ function for each of the five societal systems, it does not follow that the individual $Q.L._i$ metrics can be combined to provide a single measure of overall quality of life. Although in the long run this might be desirable, from a transportation standpoint it is sufficient to define a metric for each system.

It does appear possible to develop a performance measure for the major societal systems. It further appears feasible to model the performance of these systems. This, in fact, has been done for at least four of the five systems: food, housing, health care, and public safety. In essence, any of these systems can be analyzed to determine the operations underlying its performance and the criteria for performance effectiveness. As an abstract model, such determination will allow the definition of the maximum or ideal quality of life that each of these systems can provide within the current state of the art.

In the context of this program the reason for conducting these systems analyses is to relate the quality of life output to transpor-

tation, or more generically, accessibility. If accessibility is an important determinant of societal system performance, then allocation of resources to or the design of transportation may be rationalized by its incremental improvement in quality of life. That is, the objective is to define the performance characteristics of accessibility required by a societal system which can satisfy its objective function: the quality of life it can provide. The proposed approach requires a non-modal analysis of the performance requirements for linkage within each societal system. Clearly, these requirements include a wide variety of linkage requirements including capacity, scheduling, routing, ride, handling, command and control. To reiterate, the objective is to define operational linkage models so that all possible technologies for satisfying the demand placed upon systems may be evaluated. This approach is a fairly common one in high technology areas and provides a basis for system concept definition.

This discussion has been concerned with the structure of the societal systems from the providers' standpoint. However, the effectiveness of any of these systems in providing its maximum quality of life is ultimately as dependent upon the consumers of the services as it is on the provider. In almost every societal system, utilization is consumer initiated. In this sense, the societal systems are passive in that they are deployed or ready to be deployed, waiting for the consumer to trigger them into action. Thus, how the consumer perceives or chooses to use the societal system will determine the actual quality of life that any system, in fact, does provide. For example, a citizen

witnessing a crime who is unwilling, unable or does not know how to access the police reduces the effectiveness of the police system. Similarly, an individual who does not know the location of a hospital or how to enter the system will not be able to make effective use of that system. Hence, the quality of health care will be decreased even though the capability exists to treat the individual.

It becomes obvious from this discussion that we may state a general model for the quality of life that any societal system can provide. It may be defined in either of two ways. One is:

$$Q.L._i = (Q.L._i^A - f(D_i, C_j^k C_j^A) \tag{1}$$

Where $Q.L._i$ = the actual performance of the system

$Q.L._i^A$ = the maximum performance of the system

D_i = delivery efficiency

C_j^k = consumer knowledge of system

C_j^A = consumer access efficiency

The other is a relative model, i.e.:

$$\frac{Q.L._i}{Q.L._i^A} = f(D_i, C_j^k, C_j^A) \tag{2}$$

That is, the proportion of the absolute quality of life a societal sytem can provide at any point in time is dependent upon its delivery

capability, consumer knowledge of how to use the system and the consumers' capability to access the system. Obviously, the functional form of the model is not determinate at this point other than to say that it is a stochastic one. One of the major tasks in the proposed research program will be to develop the analytic structure. The real concern in this phase of the effort is not modelling the component parts. Rather it is their combination, linear or nonlinear, additive or multiplicative that is the difficult analytic problem. At the least it should be possible to develop the three models independently to produce a method for generating an output in terms of a quality of life measure. It is possible to exemplify the nature of the process that would be the product of this program with a concrete example. This will be done using health care and specifically emergency medical care.

For accidental trauma, cardiac, vascular and certain organ failure, the criterion for survival is the total time delay to between the trauma and the initiation of treatment. The survivor curves are negative exponential distributions of the form:

$$f(t) = re^{-rt} \tag{3}$$

If this function is integrated over some time interval from the time of occurrence of the trauma event, then the proportion surviving can be determined as a function of delay to treatment. Each category of trauma may have a different value for the parameter, r.

If one analyzes the components of delay to initiating life saving treatment, one finds three categories of delay. One is consumer induced delay. A second is a transport induced delay. A third is a supply induced delay. The first is caused by consumers having to find a means of initiating a response from the health care system. The second is the complex of dispatch and travel time delay within the health care system. The third is a delay induced by the unavailability of service within the health care system, e.g. lack of ambulances or lack of staff or facilities for treatment. It turns out that if one analyzes the components of delay to treatment, one finds that in urban areas especially, the dominant delay component in current operations is the travel time of the emergency medical care unit.

Existing data indicates that approximately 25% of the victims of trauma could be saved if treatment were initiated instantaneously. Seventeen percent could be saved if treatment delay were ten minutes or less; 13.1% with a 20 minute delay; and 5% for a delay greater than 40 minutes. At present the average delay to treatment within the health care system is 45±20 minutes. Consequently, one can estimate the relative quality of life for medical emergencies as:

$$\frac{Q.L._i}{Q.L._i^A} = \frac{k\exp{-k}\ (C_d + D_d + HC_R)}{Q.L._i^A}$$

Where

$Q.L._i$ = The proportion of lives saved in the present system

$Q.L._i^A$ = The maximum proportion that could be saved

C_d = Time delay in consumer response

D_d = Transport delay

HC_R = Medical response delay

Since the maximum proportion of lives that can be saved in medical emergencies is 0.25 and since the numerator defines a negative exponential of time, with the current system the proportion of lives that can be saved being 0.06. Hence the relative quality of life provided is 0.24. In this case C_d & $H.C_R$ are negligible compared to the service delivery delay, D_d. Clearly, then, the quality of life that the health care system can provide for medical emergencies is constrained by two major variables. One is a transport capability and the other is the geographic distribution of health care facilities. The latter is important simply because the total travel time is in part determined by the distance of the victim from a source of treatment. It should be noted that this whole system may be defined as a single queue multiserver queing model. It can be used not only to optimize the numbers of transport vehicles but also to optimize the deployment of the emergency medical care system in any geographic space. Changes in transport and/or deployment that produce a reduction in treatment delay can be evaluated using such a model to determine the improvement in quality of life for emergency medical care.

This example simply defines societal system effectiveness under the current operation of the health care system and demonstrates the critical importance of accessibility to the quality of life that system can provide. From a transportation planning and policy standpoint as well as a land use planning standpoint, such an analysis provides insight into both the effectiveness of transport performance and insight into the priorities for improving transport supply, operations, and organization.

Another way in which to view the proposed methodology is shown in Figure 1. In the figure, it is assumed that two elements are combined to produce the quality of life. These elements are delivery efficiency (D_i) and consumer access efficiency (C_j^A). Delivery efficiency in this context means the output of the societal system, e.g., quality and amount of health care for health care systems, or quantity and quality of food for food distribution systems. The further away form the origin, the greater the amount of delivery efficiency provided.

Since the quality of life is related to accessibility to these systems, consumer access efficiency is shown on the abscissa, with greater amounts of access corresponding to greater distances from the origin. The greater the delivey efficiency and consumer access efficiency, the greater the quality of life provided.

The lines labeled $Q.L._1$, QL_2 etc. show different levels of quality of life provided by the two inputs to the system. Each line shows alternative combinations of D_i and C_j^A which yield the same level of quality of life. The figure assumes that the same level of quality of life can be obtained through the use of less D_i and more C_j^A or vice

versa. The line labeled QL^A shows the maximum quality of life that can be obtained from the system under current technology.

These iso-quality of life lines are drawn convex to the origin. This shape assumes diminishing returns to increases in one type of efficiency holding the other type of efficiency constant. In addition, the figure assumes that consumer knowledge of the system is constant.

This figure shows how the quality of life can vary across locations as a function of the level of accessibility provided. Suppose the delivery efficiency of a societal system is at the level D_1. Two residential locations have different levels of accessibility to the system: ${C_1}^A$ for the first location ${C_2}^A$ for the second. Consumers located at the second location would have a higher quality of life (QL_2) than the first (QL_1), even though the delivery efficiency of the societal system is the same for both locations.

The effect of current practice in planning societal systems and transportation systems can also be illustrated in the figure. Current practice is to plan the transportation system independent of the societal system. Thus, planners of the societal system can increase the quality of life by increasing the delivery efficiency to D_2. The quality of life of consumers at both locations has increased. Alternatively, transportation planners can increase the quality of life by increasing consumer access efficiency at each location, given that delivery efficiency is held at the level of D_1. Thus, the quality of life at the first location can be increased to QL_2 by increasing its access efficiency to the same level of consumers located at the second location.

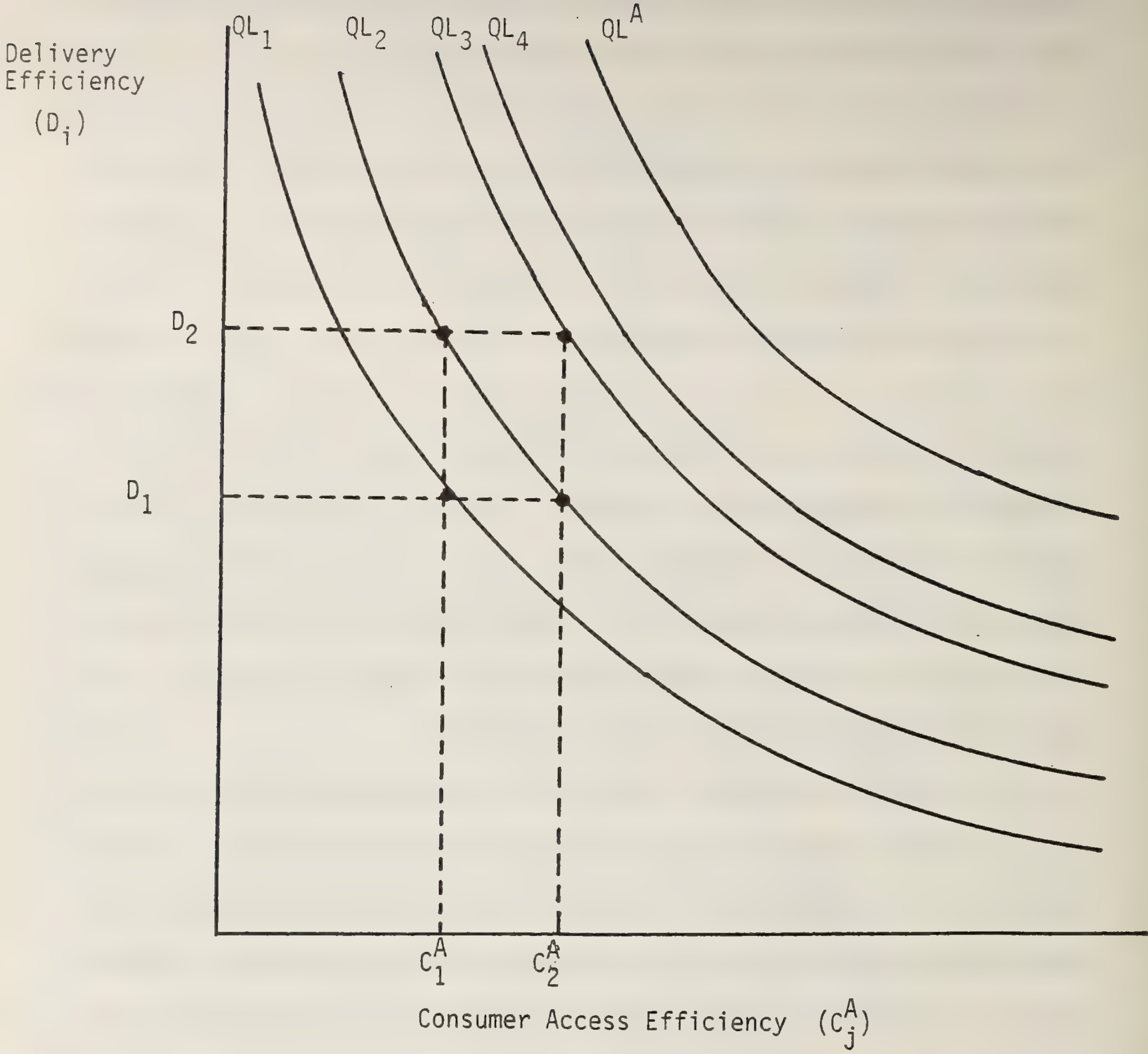


Figure 1: Relation between quality of life, accessibility and delivery efficiency

Current practice, however, is inefficient, in that the same quality of life could be obtained with the use of fewer resources, or alternatively a higher quality of life could be obtained with the use of the same resources. This efficiency can be reduced or eliminated by planning both the societal system and the transportation system together. This proposition is illustrated in Figure 2.

In the figure are shown two lines B-B and B^1-B^1, which are superimposed on the iso-quality of life lines shown in the previous figure. These lines are iso-cost lines. The slope of each line is the ratio of the cost of providing increments to delivery efficiency to the costs of providing increments in consumer access efficiency. Thus, each line illustrates the costs of increasing delivery efficiency relative to the costs of increasing accessibility. The further the distance from the origin the greater the amount of resources devoted to both delivery and consumer access efficiency.

The situation illustrated in the previous figure for the first location is shown as point I on the figure. The first consumer location could experience a higher quality of life if fewer resources were used to provide delivery efficiency and more resources were used to increase the accessibility of the location to the societal system. Point II illustrates this result. In addition, if both transportation and the societal system were planned together, it is possible to keep quality of life at the same level, and reduce total expenditures to B-B. Point III is an illustrator.

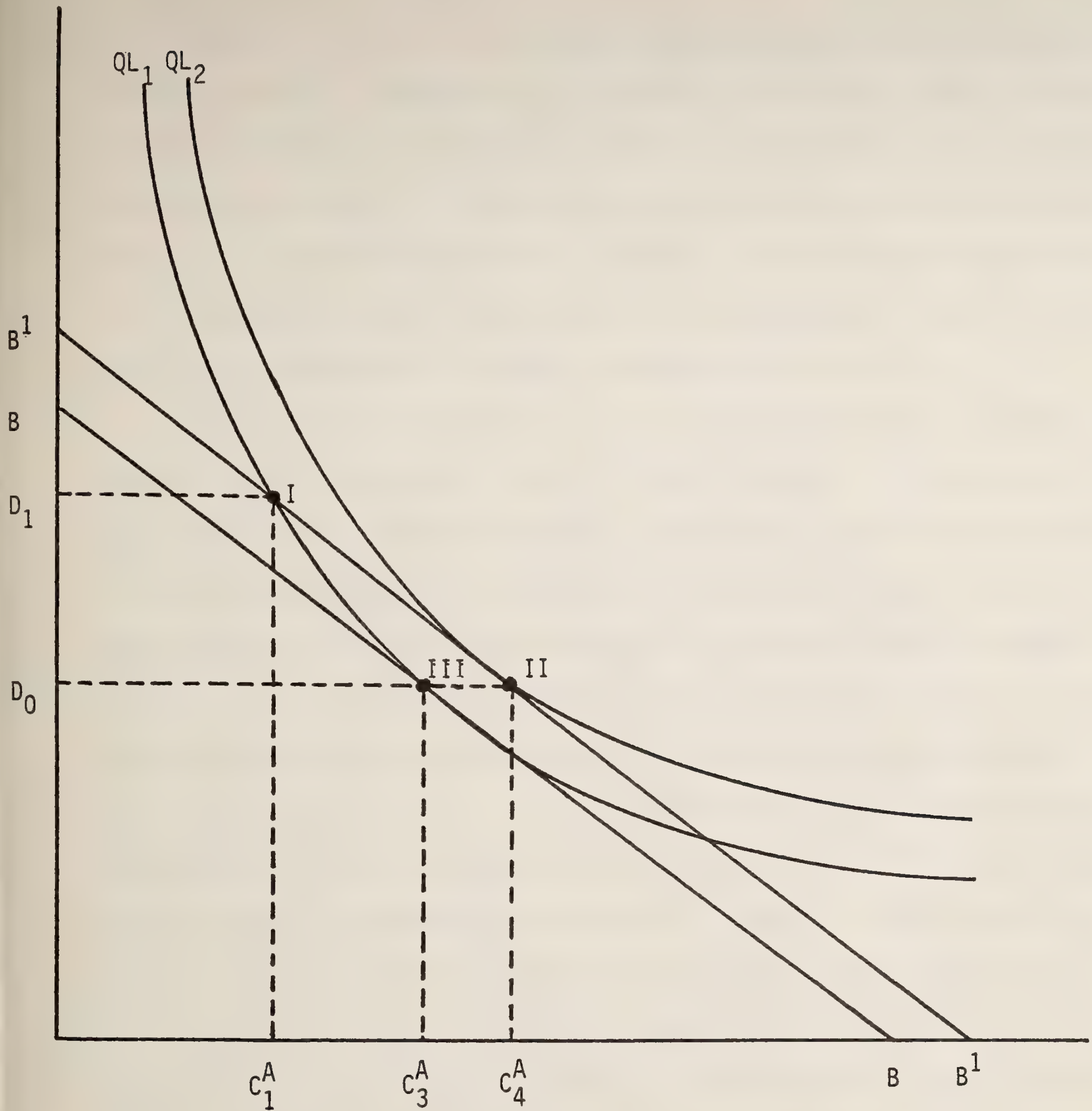


Figure 2 - Quality of life and costs
of providing it.

Viewed in this way, the societal systems approach can provide the foundation for a transportation planning methodology. This approach permits a more efficient allocation of resources to both transportation and societal systems. In addition, consumer locations can be ranked on the basis of the quality of life provided. Locations with low quality of life due to access inefficiency can be improved. Thus, a more equitable distribution of transportation services can result.

This discussion has focused on the consumption side of providing goods and services that is, on the output function. In essence, the model structure subsumes the person movement sector as far as transportation is concerned. It should be obvious, however, that a complete model must include the "goods" movement or production side of transportation. To be concrete, the quality of life obtainable by a consumer from the food system is determined by the production and processing of agricultural products and on the mechanics of the distrubution of those products. It is well to note that the quantities produced, in what form and how they are distributed are known in detail. Further, they are known for each of the societal systems. Finally, they are known in terms of regional flows. There is, however, only limited information about detailed intra-regional flows, e.g. urban goods movement. Thus, it is possible to model, starting with the final output of the societal systems, the material flows required by them to provide consumers with goods and services, i.e, a given quality of life. In essence, the question is: How does the production and the distribution process (which includes location) affect the quality of life that the soci-

etal system can provide? The answer to this question is a necessary element in developing the basic measure of system preformance as well as providing the basis for defining the freight (or information) movement requirements for each system.

As was noted at the outset of this proposal, the objective of the effort is to develop an abstract (in the modal sense) model for transportation. The basic focus is on accessibility, both accessibility of materials, information and manpower to providers of societal services and accessibility of the products of these systems to consumers. The modelling activity must be abstract because the quality of life that can be provided depends not only on transportation but also on deployment or location of the provider as well as on general land use considerations. In this sense the approach discussed is essentially a model of social organization. Its aim is to model three linkage elements: 1) the inputs of goods and labor required for an outlet to provide services to consumers; 2) the mechanism by which consumers obtain services; 3) the spatial distribution of outlets for goods and services essential to satifying the performance requirements for delivery of those services.

The research program that is described in the following sections is designed to develop these three models. As was mentioned earlier, there are five societal systems that have definable and quantitative objective functions. Of these we propose to use three for development of the methodology. One is the food system. Second is the health care system. third is the public safety system. The first is selected because it is a private sector system whose operating characteristics including outlet

deployment are determined by classic economic criteria. Health care is selected in part because it is a noneconomic system for which extensive analysis of its operations have already been done. Public safety is selected because it is a public system for which extensive operations analysis has been done, especially spatial organization. In essence, functional models as well as detailed operations analysis have been done for these three societal systems. Consequently they are the most direct ones to use for determination of the relationship between accessibility and system performance and hence for development of a general accessibility model. Further, such a model will allow a better understanding of the relation between spatial organization and transportation. Finally, given such a model it will be possible to examine and evaluate alternative transport strategies relative to the performance of those systems.

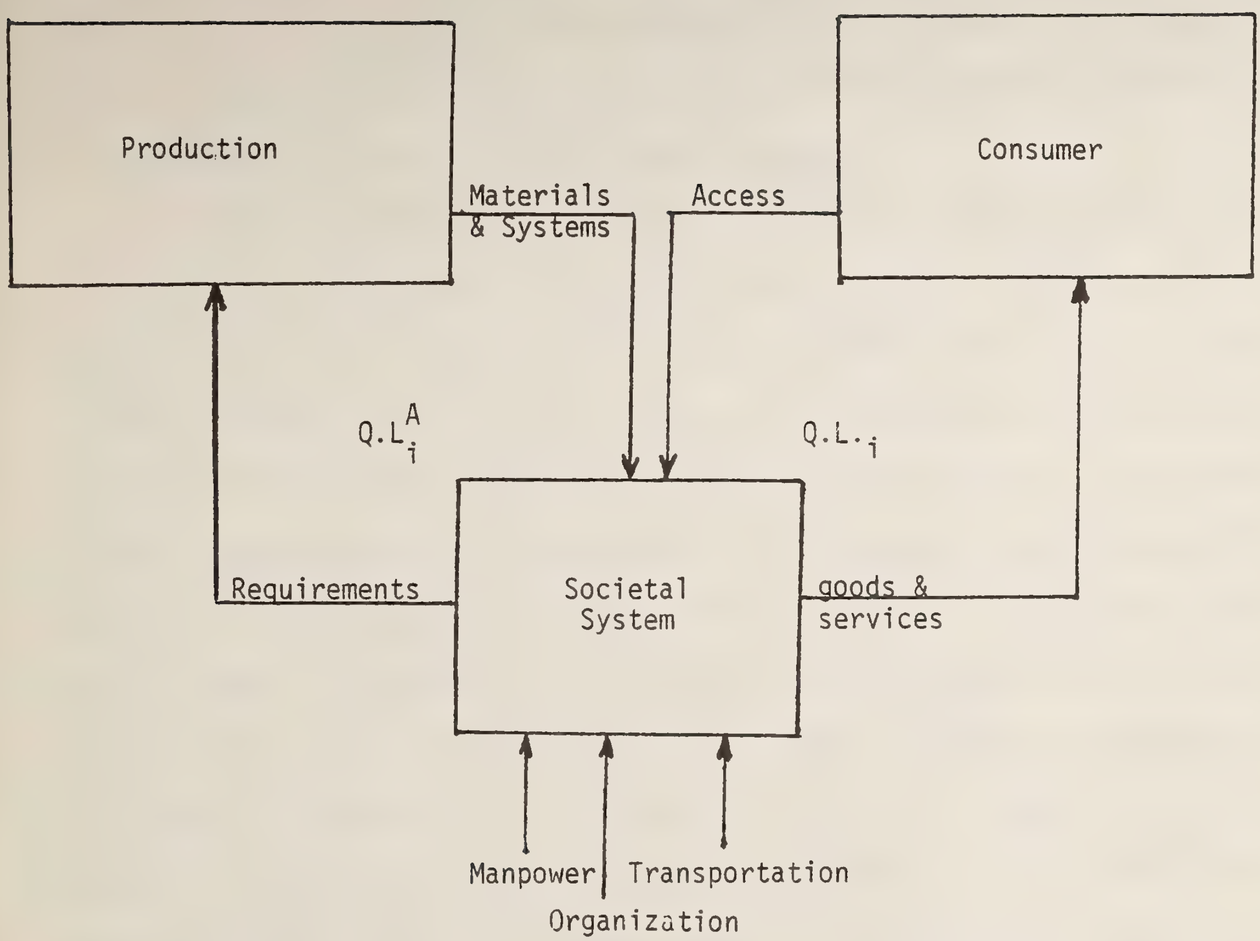
Finally, it should be noted that our approach to modelling transportation starts form the consumption function and works back ultimately to the production side. This is the reverse of the historical development of transportation and its planning which has been primarily based on satisfying production system requirements, i.e., freight and labor movements. Although these must ultimately be contained within the structure of the transportation policy and planning process it is our view that these requirements must be derived from the societal sytems. This is simply because production, like transportation, is a service system whose rationalization is its contribution to quality of life.

A. INTRODUCTION

As a basic paradigm for this research program, we see the problem as composed of three interrelated elements, the focus of which is the societal system. This is shown in Figure 1. The loop between the societal system and production defines the maximum performance of the societal system, i.e., the absolute quality of life the system can provide, $Q.L._i^A$. The loop between the societal system and the consumer defines the actual quality of life obtained, $Q.L._i$. Thus the absolute quality of life that can be provided is determined by the goods, materials and technology that the production system can both generate and deliver. It also depends upon the reliability of those materials as well as on the reliability of their delivery. In addition, the absolute quality of life a societal system can provide is determined by the availability of the requisite manpower and by the organizational structure of the system itself. An essential and determining aspect of the absolute quality of life that a societal system can provide is the logistics involved in service delivery. It is this logistic function that is the focus of the modelling in the three systems under study.

The consumer side is concerned with the means by which the system is used. The demand for goods and services is in part determined by the the consumer's knowledge of the societal system, the demand for such services and the social and physiological differences within the

Figure 1


Production
Consumer
Materials & Systems
Access
Q.L^A_i
Q.L.$_i$
Requirements
Societal System
goods & services
Manpower
Transportation
Organization

population that determine whether, when and how the system will be used. An underlying determinant of the utilization of the societal system is the real and perceived accessibility of the goods and services available. Again the focus of this program is on the spatial and temporal aspects of access to the societal systems and their functional relation to the quality of life obtained by the consumer.

The research program is designed to analyze the three systems, food distribution, health care and fire protection services. Its objectives are threefold: One is to define the objective functions of each of the societal systems, how those objectives are met, and the accessibility necessary to meet those requirements. This should allow us to model the linkage properties of the production side of societal system performance. A second objective is to analyze the consumer demand for the services and the requirements for accessing the systems. This must include both the real and perceived requirements. Within some taxonomic structure of consumers, we will develop a model of access by system users. A third objective is to integrate the production and consumption models to define a ratio or interval model relating accessibility to a quality of life measure.

In order to satisy these three objectives, five technical tasks will be required. The following sections describe each of these components of the effort.

B. The Research Tasks

Task 1. Societal Systems Analysis

Each of the three systems will be analyzed using conventional systems analysis techniques to determine their basic organizational and functional structure. The fundamental goal is to operationally define the objective functions of each system. This will be done first by examination of the basic literature in health care, fire protection and food distribution planning. Some of the basic literature is contained in the appendix.

A second element of this task is to identify the requirements of each system to satisfy its objective functions. This requires an analysis of the organization of each societal system to determine the manpower, material and equipment needs essential to their satisfying their objective functions. Again for the three systems under study, there is sufficient literature to accomplish this task. The major problem will be to relate these requirements to some demand function. This ought to be the basic criterion for sizing a particular societal system and for its location. We doubt, however, that this is empirically the case. However, for health care and fire protection there exist ample data to model the process idealistically.

A third element of this task is to develop some measure of the quality of life that the societal system can provide. This will allow us to develop a measure of the maximum benefits that the system can

provide. We expect this measurement to be straightfoward for fire protection since the benefits are determined by two factors: 1) the time delay to fire control; and 2) the availability of appropriate manpower and equipment. If we let the time delay be zero, it should be possible to define the minimum loss function. For health care, the problem is significantly more complex. However, the national health statistics provide comprehensive classification of major disease processes. Using these it should be possible to determine "cure" rates and time necessary to "cure". For the food system the problem is more even more complex since demand for food is confounded by consumer taste. However, detailed data on consumption is available from government and private sources so that reasonable demand functions for different commodity classes needed to satisfy essential nutritional needs should be determinate. Hence it should be possible in all three cases to define a measure or measures of the quality of life that the system can provide.

Task 2. Societal System Accessibility

In order for the societal system to provide its goods and services, it must have two kinds of linkage. One is availability of those goods and materials essential to provision of services. The other is the labor essential to its operations. Both aspects are a classical logistics problems involving both inventory and replenishment. It also includes acquisition of new equipment and facilities. It should be possible in the case of all three systems to employ existing production system logistics models to determine the temporal and quantitative

process of material supply. Much of the base data to define such a model is available in the existing literature, and we would propose to use as much of that as is possible. However, where necessary this data will be supplemented by data obtained locally. UICC has worked with the Chicago Fire Department as well as with the University of Illinois Medical Center and believes that both can supply any specific additional data we may need.

Task 3. Production Systems Analysis

The societal systems require goods, materials and technology from the industrial network which is designed to support these systems. It is the requirements of the societal system that define the quantity and quality of goods produced by the production sector. In essence, a significant fraction of freight flows within the United States are in response to the demand of the societal system. Further, the absolute quality of life that each system can provide is determined in part by these freight movements. The purpose of this task is to determine the magnitude of these flows to each of the societal systems and their temporal and spatial distribution. The flow magnitudes are readily available from the Bureau of Labor Statistics and the Bureau of Economic Analysis. These are known in detail by commodity class and industrial sector. Further, knowing the geographic distribution of societal system facilities which can be readily derived from existing land use data, it will be possible to distribute the goods movement quantities within a region. From a transportation planning standpoint, it is intra-regional goods movement that requires modelling rather than interregional. The

objective of this task therefore, is to determine the demand for goods and materials by the societal system and then aggregating. The model produced will be a relatively simple one for allowing the dimensioning of the quantities and spatial distribution of intra-regional goods flow. With this information it will be possible to apply conventional logistics models to define mimimum cost distribution. In sum, the output of this task is to provide a goods movement sub-model which will define the quantities and flows necessary to support the societal system without compromising its ability to achieve its absolute quality of life production.

Task 4. Consumer Analysis

We will define the consumer of societal system goods and services as a deficiency satisfying entity. We are fundamentally concerned with how those needs are fulfilled and how individuals exploit the social organization to satisfy their needs. Obviously, needs are the essential determinant of demand, for they define the frequency with which any individual will make a "trip". It should be noted that this definition of demand is an absolute one any may bear little relation to revealed or observed travel demand.

At the same time, for any need to be satisfied, an individual must be able to locate a site where it may be satisfied. That is, there must be places, devices of systems <u>known</u> to the individual that will provide the desired need satisfaction. Thus, in conventional terms, trip distribution and trip generation are coupled. Furthermore, there is

no essential relation between trip generation, i.e., movement to satisfy needs, and macro-geography of trip ends. That is, a wide variety of needs satisfiers are transported to the individual.

It follows, therefore, that needs and the sources of their satisfaction are linked subjectively. In addition, need satisfaction is conditional on accessibility. That is, there must be means to link the need to its source of satisfaction. However, such linkage must be defined as a cost in the process of need satisfaction for it consumes time and energy and thus delays satisfaction. In essence, linkage may be conceived as an opportunity cost.

An operational consumer model for transport, i.e., one that provides an estimate of the trade-off cost for obtianing goods and services, requires development of a functional relation among three classes of variables: 1) need structure 2) activity site selection; and 3) access cost. The focus of this task is to develop such a model.

Element 1: Quantification of Need Structure

Needs are the underlying motivator of behavior. It is their satisfaction that defines trip generation. The definition of needs is well developed in the behavioral sciences. What is not defined is their specification in terms relevant to societal systems. However, from our analysis there are four classes of needs that can be defined which can be associated with each of the societal systems. These are: 1) physiological; 2) psychological; 3) social; 4) support. Physiological needs are the essential bodily and physical requirements for stable

existence. Examples are nutrition, health, metabolic balance. Psychological needs are those essential to individual qualitative well being. Examples are security, safety, order, reliability. Social needs are the interpersonal transactions required to assure the sense of belonging, participation and involvement with others. Examples are group involvement, social relations, familial attachment. Support needs are derived requirements for stabilization and maintenance of the environment. Examples are shelter and shelter related systems, durable goods acquistion, and support services.

The modelling problem is not the specification of this set nor connecting them to the set of societal systems. Rather it is one of modelling their temporal and spatial qualities to define a measure of a time-space demand. This is true simply because needs vary in intensity over time in a cyclic or random fashion. It is this "need strength" which ultimately determines the probability of a trip. For cyclic needs, a large fraction of the total set, it is obvious that the individual may plan for their satisfaction. Indeed recent evidence (Jones, 1979) suggests that individuals do organize their time and energy in ways that assure that their needs are consistently satisfied. In this sense, the individual acts as an inventory system. If we know the rates at which need strength reach some action threshold, it should be possible to develop an inventory model that defines trip frequency. In fact, this development appears fairly straightfoward since it requires an integration of household behavior and time budget studies (Dix, 1978; Chapin 1969). For needs with random occurrence, which

are typical of support needs, failure rates of support systems would be a direct basis for modelling their frequency.

Using either an information integration (Anderson, 1970) or a utility approach (Luce, 1957) it should be possible to develop a "trip" generation or general demand model. The objective in this element is to define such a model in terms of the societal systems as the source of need satisfaction. Finally, it should be noted that such a model would provide an estimate, in the probabilistic sense, of the absolute or total desired participation in activities, regardless of cost or accessibility. In fact such a model has been developed (Michaels, 1978) and it also includes an accessibility weighted demand component.

Element 2: Activity Site Selection

In practical terms it is not conceivable to consider needs outside of their means of satisfaction. That is, perception of needs is conditional on there being means for their satisfaction. There is then a direct connection between the desire for some activity and the avialability of some site for its satisfaction. The perceived availability of a societal system is in part a determinant of a trip being made. The probability of a trip being made then must depend on three variables: 1) the need strength; 2) knowledge about the satisfier site; and 3) the perceived costs to obtain satisfaction. The first has already been discussed. The second refers to the cognitive field of the individual; that is, the understanding of the location of satisfier sites in time and space and their differentiation as means of satisfying

needs. The third refers to the trade-off between need satisfaction and the composite costs-physical, psychological, temporal and economic to be incurred. In essence, travel to a particular site by an individual can be defined:

$$T_{ij} = f(S_{ni}, A_j, C_{ij})$$

S_{ni} = need strength

A_j = satisfier site characteristics

C_{ij} = accessibility cost

If utility were used as the basic criterion, we could define the probability of a trip to a particular location (T_{ij}) as the likelihood of the perceived utility of a site relative to the perceived disutility of accessing and using that site. This kind of model is based upon the opportunity cost to satisfy a need. Thus the higher the percieved cost to satisfy a need the higher must the need strength grow in order for a linkage to be made. Obviously, the first part of the equation depends upon the individual's cognitive structure, his perception of the sources, locations and characteristics of need satisfiers. The purpose of this task is to define a functional relation between needs and satisfier alternatives. Such a theoretical model (Michaels & Wright, 1972) has been developed based upon the utilities of the site and the utility (really disutility) of travel. This represents a starting point for a class of distribution models in which the "cost" of travel is an integral part.

Element 3: Access Requirements

For any individual to satisfy a need at a desired satisfier location, that individual must have a linkage capability, direct of mediated. The nature of the process of linkage defines whether needs may be satisfied and how well. The issue is the nature of the linkage required and the generic "costs" to obtain access. The first is concerned with the properties of the transfer which must be one or a combination of three elements: information, goods and persons. Part of this task is to disaggregate this transfer set that the consumer must use so that the structure of access requirements may be defined.

The second is essentially concerned with the opportunity cost of access. There is a time, energy and economic price for need satisfaction. If the access cost is tooo high relative to the need strength, the individual will not act to satisfy the need. Conversely, as access costs are reduced more needs will be satisfied. The limit is simply determined by the time and resources of individuals as well as their ability to organize their time. Thus there must be a relation between need strength and percieved access cost. It is reasonable to assume that this relation may be represented as a logistic function. However, for a wide range of need strength, it may be that access cost is practically constant and low. This would certianly be the case where satisfier sites are immediately accessible. The issue is to define the characteristics of this function. In the context of the quality of life criteria, it is this cost-need strength relation which determines the actual quality of life that any individual will obtain within a given set of societal system alternatives.

Element 4: Population Stratification

The model discussed in this task implies homogeneity of consumers. This, of course, is not a valid assumption except in the context of absolute demand for need satisfiers. In reality, there are considerable differences between people in how, when and where they will satisfy their needs. There appear to be at least four dimensions along which this disaggregation may be defined. They are: 1) in cognitive development; 2) stage in the life cycle; 3) resource availability; 4) psycholophysiological status. It turns out that these four dimensions have been studied in detail (Rees, 1970; Michaels & Weiler, 1974). The purpose of this task is to develop the definition of these dimensions and to develop a means of relating them to readily available data bases, e.g, census and land use. The ultimate objective is to develop a procedure for defining zones of homogeneous social structure that can be used for both transportation modelling as well as for planning and analysis. Finally, this taxonomy will serve as the stratification dimensions for the application of the consumer model to define the actual quality of life obtained.

Task 5. Integrated Model Development

This final task involves integrating the societal systems, production and consumer models into a coherent model structure capable of becoming a framework for a societal systems approach to transportation planning. The rough outlines of such a framework are shown in Figure 2.

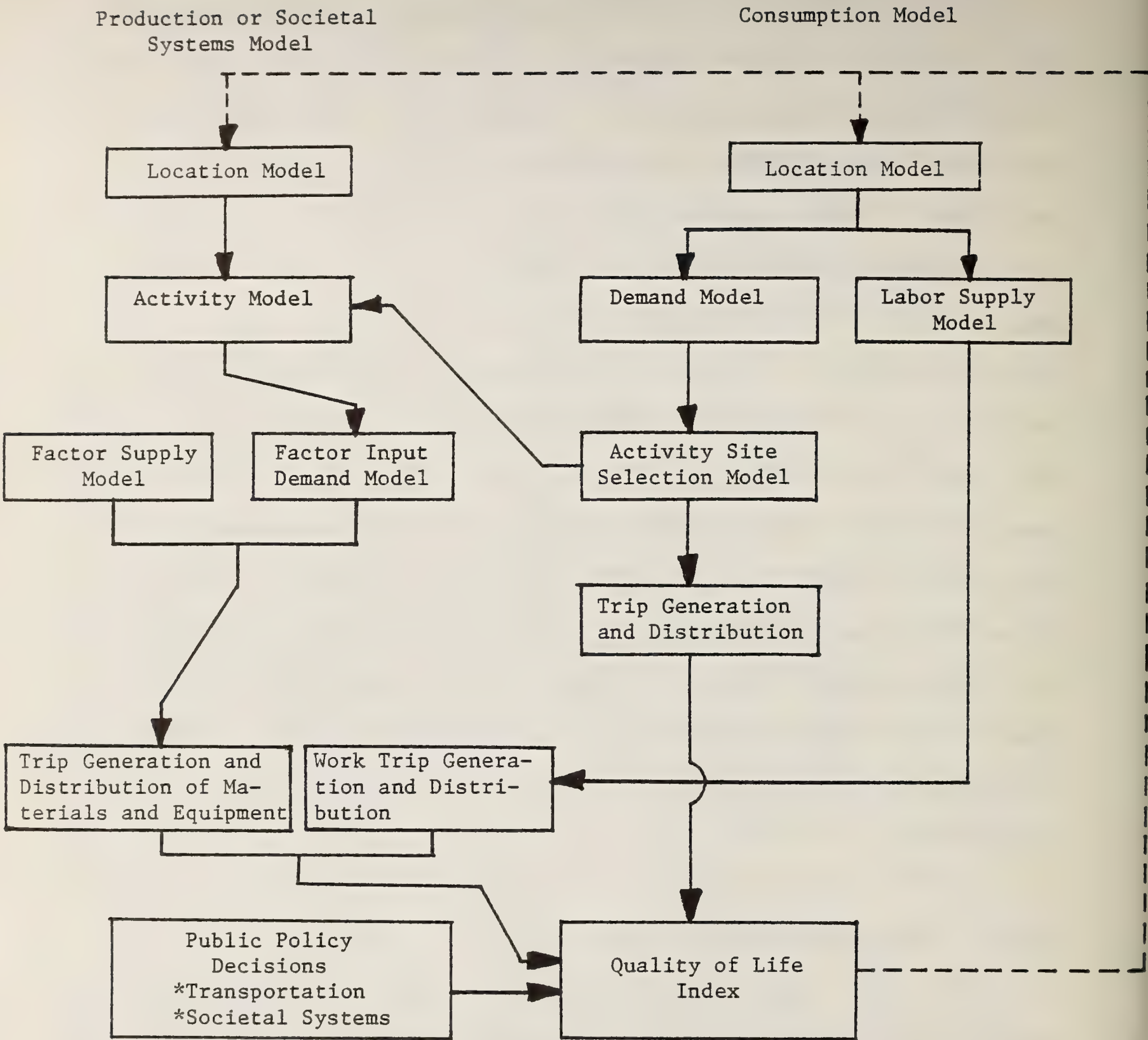


Figure 2 - Framework for Societal Systems Approach

As illustrated in the figure, seperate, but yet parallel modelling efforts will be undertaken in the production, societal systems and consumer areas. Although differing as to details, the overall model for production or societal systems is similiar thus only one framework for those systems is shown. The consumer sector differs somewhat from the other areas, and so seperate model segments are shown.

The initial step is to specify a location model. At this point, a distinction must be drawn between short run and long run planning models. A short run model will be defined as one in which locations of production facilities, distribution facilities, societal systems locations and residential location patterns are fixed. Thus, the short run location models will merely be a statement of the location of each of these facilities and residences. Although the exact specification is beyond? the long run planning models will assume that facilities location patterns may change within the urban area. The production systems location model will draw upon the industrial and retail location literature such as the work in relatively by Holly and Wheeler (1972) and Huff (1964). The residential location model would draw upon accepted theories of residential location such as the work of Muth (1969). Locations of societal systems facilities is a matter of public policy choice which probably will be assumed to be exogeneously determined.

The demand model and the labor supply model are both the result of the consumer analysis. The demand model would specify the demand or requirements for the goods and services. Although beyond the scope of

the initial phase of the work, the labor supply model would indicate the types of labor available in various locations throughout the urban area.

The activity site selection model will then distribute final consumption for societal systems outputs and for the outputs of production systems to the specific locations of these facilities. The modelling effort will utilize a variation of the approach presented previously along with the integration of existing methodologies such as the work of Bacon (1971).

The activity model for both the production and societal systems will be one of the products of the societal systems analysis and production systems analysis tasks. Along with the activity site selection model, the output of this model will be the level of activity for each system at each location (e.g., amount of food sold, No. of patients treated).

The demand or requirements for labor, capital equipment, and raw materials is the major output of the factor input demand model. Factor input demand is a derived demand derived from the demand for the output of the system in question.

The factor supply model will indicate the spatial distribution of the raw materials and capital equipment used in the societal system or production system in question. This model is the activity model of other production or societal systems which supply inputs to the system in question. For example, in the case of health care, the model would indicate the sources of supply of drugs, x-ray equipment, etc.

The next components are the trip generation and distribution models. The previous components can be considered as static equilibum models or parts of status models. The trip generation and distribution models, on the other hand, will be developed as time dependent dynamic models. Trip genertion and distribution in the consumer sector and in the production or societal systems sectors will depend on a logistical cost analysis in which tradeoffs such as the one between transportation costs, and inventory holding costs are evaluated. The concept is to determine the number of trips which minimize total logistics costs. The work trip generation and distribution model utilizes inputs from the factor input demand and lobor supply models.

The model components will then be used to develop a quality of life index for each production or societal system. An aggregative quality of life index for residential locations can also be a product of this analysis.

Public policy decisions concerning transportation and societal systems will have an effect on the quality of life produced by each system and the overall quality of life of particular residential locations. This is the point in the model structure in which the effects of transportation improvements can be analyzed.

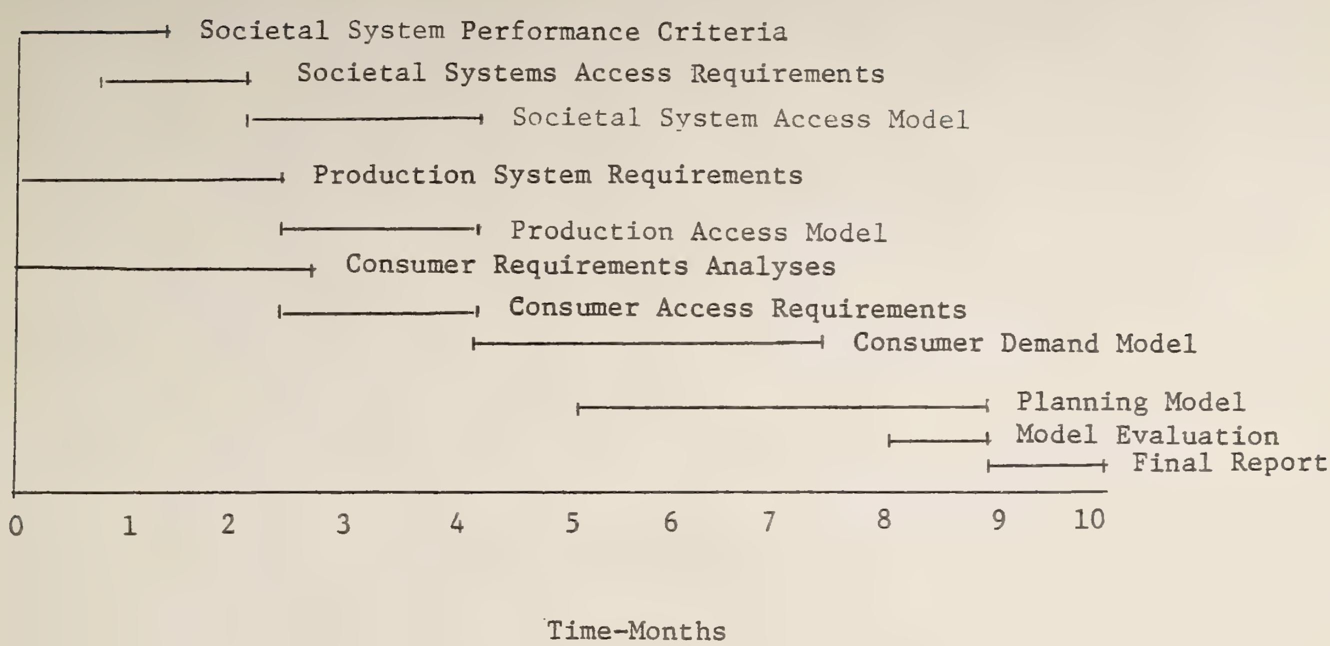
It is envisioned that the integrative model will be able to evaluate the effects of public policy decisions on location decision, once adequate location models have been specified. The dashed line illustrates this concept.

Pages 31 through 33 have been deleted.

A. Project Time Phasing

The basic program contains ten elements to be completed in a total time of ten months. The ten elements are divided among the five tasks: 1) societal systems analysis; 2) societal system access requirements 3) production requirements analysis; 4) consumer analysis; and 5) general model. The detailed time phasing is shown in Figure 3. Two things should be noted. One is that modelling the consumption process requires 7 months; this time allotment reflects what we consider the most difficult modelling activity. Two is that forty percent of the time is devoted to the formulation of the integrated model; this activity will begin before the consumer modelling is complete. This decision reflects the fact that the societal system and production side models will be reasonably complete by the end of the fourth month. The review of the literature on these systems and the criteria for their performance suggest that both data and analytic procedures are available.

Fig. 3 - Project Time Phasing



Appendix A

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APPENDIX C

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new technology, has led to several innovative concepts for analyzing transportation/societal interactions. Societal systems, societal linkages, quality of life systems, delivery efficiency, and consumer access efficiency were introduced as concepts for modelling the interactions among transportation, production, and societal systems.

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Residential Housing and Location Model

Methodology for Comparative Analysis of Urban Spatial Structures

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Probabilistic Systems Dynamics Model

Micro-Economic Model

Societal Linkages Model

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